Chemical Engineering Progress

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LETTERS TO THE EDITOR

More on Sherwood Number

Regarding the naming of a new dimensionless number in honor of Professor T. K. Sherwood. . . Although in general I think we have enough names for dimensionless groups, in this case it would be very appropriate to honor a representative of the U. S. school of chemical engineering in such a way. Tom has contributed much to transfer theory and application. All of the other dimensionless groups are named in honor of European investigators. I would, therefore, cast a vote in favor of naming the number given by Professor Sage the "Sherwood number" as he recommends.

J. C. ELGIN

Princeton University
School of Engineering
Princeton, N. J.

Kohlins on More

One of the really valuable things that the A.I.Ch.E. can do for the chemical industry is the establishment of equipment testing procedures. I was therefore glad to learn that there is now available "Standard Testing Procedure for Heat Exchangers." This is something that probably most every chemical engineer will want. The committees charged with developing testing procedures for other types of equipment should be encouraged to publish their results so that they too will be available to practicing chemical engineers.

There is, however, one thing disturbing to me. This concerns the charge for Testing Procedures of 25 cents for a member and 50 cents for a nonmember. It seems to me that such data should be supplied to members without charge. There certainly is justification to charge nonmembers but to charge members for a service which the Institute should render does not seem to me

LETTERS TO THE EDITOR

(*Continued from page* 4)

to be proper. I also feel that preprints of various symposia should also be furnished to the members without charge. In both cases, I am not objecting to the amount of the charge but to the idea behind it. The Institute does little enough for its members so that an additional charge for these publications seems to me to be going a little too far.

As a classic case in point, you might refer to TAPPI. I happen to be a member of this organization and just last week I received a bound book 364 pages long on the subject "Bleaching of Pulp; TAPPI monograph No. 10." This is not a paper-backed edition but a regular book which covers 15 articles together with an index. This book is sent to all members of TAPPI without charge. In addition, as a member, I receive an annual bound book giving a bibliography of paper making and U. S. patents on the subject.

In addition, every year a large number of printed loose-leaf sheets, giving all kinds of standards and testing procedures and data on the subject of pulp and paper, are sent to the membership. There is a steady stream of technical literature and data which are published by TAPPI and sent to all its members without any charge or without even a request by the member for this literature. In my opinion this is certainly a good example of a technical association serving its members, its industry, and itself. I think that the Institute could do well to attempt to follow a similar procedure.

In addition TAPPI has a large and active Chemical Engineering Committee that has done and is doing valuable and extensive work on chemical engineering operations and at no time has anyone from the American Institute of Chemical Engineers evidenced any interest in the work of this group.

As a case in point, they are now completing a long and exhaustive survey on "Corrosion in Digesters," which is certainly a matter of interest to chemical engineers and this information will be sent to all TAPPI members. It would seem to me that the Institute could benefit by offering at least to collaborate with this committee.

I do not want to hold up TAPPI as the shining example of what a technical organization should be but certainly it is far more active that A.I.Ch.E. and appears to me to offer much more to its members. For the A.I.Ch.E. to add insult to injury by making the charge of 25 cents for a "Testing Procedure" is more than the membership can be expected to take.

W. D. KOHLINS
The Blaw-Knox Co.
New York

NOTED AND QUOTED

∫ Specialist & Expert = Engineer

The dictionary defines a specialist as a person who has devoted himself to the study of a particular branch of art or science, and thereby has acquired a particular or special knowledge of the subject. The expert is defined as a person who has been taught by use, practice, and experience. . . . In the progressive life of our nation, we have need of both the expert and the specialist. It is when we find the two combined in one person that we have one of the most useful of our citizens—the engineer . . .

The worst thief of time, among a man's associates and his bosses is the fellow who takes twenty minutes of rambling discourse to tell what could be said in twenty words. There is a curious and widespread tendency among engineers to surround the answer to a simple question with so many preliminaries and commentaries that the answer itself can hardly be discerned in the verbal fog. It is so difficult to get a direct answer out of some men that their usefulness is thereby greatly diminished. The tendency is to explain the answer before answering the question.

Lewis A. Vincent
National Board of Fire Underwriters

Screening a Technical Author

People need more good scientific and technical books. We all know that scientific research is finding important new principles nearly every day. If we are to have an informed public that understands the world around us, the principles must be explained in terms of the experience that has gone before. . . .

Generally, we should raise four questions about the author of a scientific or technical book:

(1) Has he followed the scientific method, honestly and competently? . . .

(2) Is the writer a free scholar, free to tell the truth as he sees it? . . .

(3) Has his work been tested through free and open criticism by other scholars in the same field? . . .

(4) Has he the respect of competent colleagues in his field? . . .

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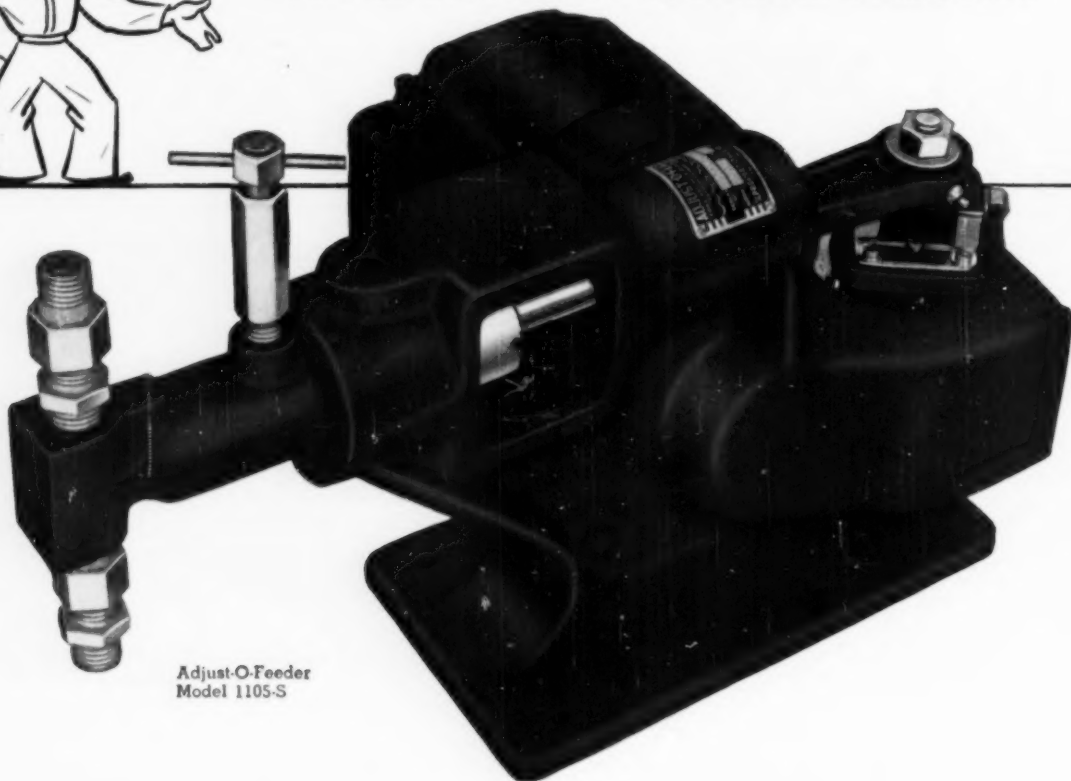
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Opinion and comment

A FRANKEN$TEIN MON$TER

A couple of years ago a most interesting discussion occurred in a hotel room at one of our national meetings. A half-dozen or so men, some of them recently returned from foreign lands, were examining the nature of capitalism as practiced in the U. S. A. and elsewhere in the world. There seems little room for doubt that our brand of capitalism is unique. Here, the capitalistic system is based upon the ideal of manufacturing and distributing as much goods as possible to as many people as possible at the lowest possible price. This system evolves from free enterprise and free and unlimited competition. Our antitrust laws are accepted by businessmen who understand the importance of competition. Elsewhere in the world capitalism seems to mean selling goods at the highest price the traffic will bear and achieving a tight monopoly if possible. In our capitalism we pay our employees as much as we can so they can buy the goods we produce. In other lands the capitalist system seems to keep wages and salaries at an absolute minimum so as to leave as much profit as possible for the owners of the business. In the U. S., industry is owned by an enormous number of people, and largely by small investors or by insurance companies, pension funds, and so forth that represent savings of little people. Here, some companies have more stockholders than employees. Elsewhere, industry is often owned by the state or by families or small groups of the wealthy.

It is, of course, confusing that such varied manifestations should be called by the same name—capitalism. It seems doubtful that Karl Marx and the apostles of hate would have dedicated themselves to the destruction of *capitalism as it has existed here* during the past half-century. Our system seems to be the perfect way to achieve the economic independence of the individual. It is as new in the world as the political freedom which has grown here since the Declaration of Independence and the promulgation of the Bill of Rights. No Russian, before or after the capture of the government by Communists, could possibly understand the political and economic liberty that we enjoy. The same is true for other peoples in some measure, even those who speak the same language we do.

The people of the U. S. A. are often accused of being materialistic. This means, it is supposed, that they value material things and creature comforts above intellectual and spiritual matters. This accusation very likely will always be made against those who *have* by those who *have not* and it is not necessarily true. Certainly, it may be hard for people in other countries to understand how our workers can own homes and farms, and cars and television sets, and still struggle upward toward a higher spiritual plane. They may suspect that our workers have to give up something important to achieve this comparative wealth and comfort, much as Faust had to consign his soul to Mephistopheles. The affluence of our workers has grown from political and economic freedom such as has not existed elsewhere. People not familiar with our mode of life are unable to comprehend this new phenomenon. *We are not* reduced to a lower spiritual plane because

we are well bathed, well fed, well clothed, well sheltered, and well trained to do our jobs.

We in the United States have done wonders to develop our country and our people. The results of a survey just announced by the Twentieth Century Fund reports that the United States has about seven percent of the world's population and forty percent of total world income. Some per capita incomes for 1948 were: U. S. A., $1,525; Switzerland, $950; Canada, $895; Australia, $812; Sweden, $805; Great Britain, $777; France, $418; Germany, $336; Italy, $225; Russia, $181. From these data it is at once apparent that income does not depend entirely upon natural resources or any such factor (witness Switzerland). The events of the past twelve years demonstrate to many people, at least, that the nation with the phenomenally high income, the nation which the Twentieth Century Fund's report calls the "modern economic giant" is a nation with a heart and a desire to help other nations to improve their lot (What nation ever before gave away $40 billion?). There may be ample evidence of profligacy and waste and many examples of foolish and unrealistic action in our economic assistance programs for other countries but the fact remains that our taxpayers, which is to say our citizens, bear these burdens with little or no complaint, with far too little complaint in all probability.

The Twentieth Century Fund report tells how the United States, through the Marshall Plan, Point Four, and other means has opened its technological secrets to potential competitors. Say the authors, rather gloatingly, "This policy is without precedent, just as is the present concentration of economic power in the hands of a single nation." Not only have we opened our technological secrets to potential competitors, we have exported, in addition to our "know-how," our dollars to rebuild industries to use the "secrets." What is more, much of the assistance has gone to the nations in the lowest per capita income brackets. With labor paid on so low a scale compared to ours, for example in Great Britain, France, Germany, and Italy, a revived chemical industry there will be able to undersell U. S. chemical industry right here in our own country unless we see to it that proper measures are taken. The consequence of being careless or foolhardy in this regard will be a materially reduced standard of living for our chemical workers, chemists, chemical engineers and stockholders.

Apparently, all U. S. industries are not in the vulnerable position of our chemical industry. Some big industries seem not at all concerned about tariff matters or even openly oppose tariff protection for U. S. industry. Apparently, one cannot generalize. The facts seem pretty clear in the case of our chemical industry and chemical engineers are likely to be among those most affected by tariff policies in the near future. It would probably be very much in order to have a tariff discussion at one of our spring meetings, possibly the one in Washington, to bring out all the pros and cons regarding tariffs and their probable effect on our chemical industry and on chemical engineers.

W. T. Nichols

Chemical Engineering from Soaps to Salads

E. A. LAWRENCE

The fat and oil industry covers a diversity of companies and products as broad as the similar term petroleum industry. The size of the companies and tonnage handled are far smaller and new engineering advances have consequently been slower in coming and less startling after their arrival. Nevertheless, chemical engineering and continuous processing arrived about the same time as they did in other branches of the chemical industry. Although the rate of abandonment of old processes has been slow, the changes are quite real with a marked effect on economics and product quality. As an aid in explaining why more drastic changes have not taken place as well as in understanding those that have, it seems advisable to sketch in the background of the industry.

In its largest perspective about 10 billion pounds of fatty oils are consumed annually in the United States. Of this about two thirds is consumed as food. Butter and oleomargarine run about 2.5 billion pounds of which margarine is perhaps a third. Lard, used as such, amounts to another 2 billion pounds and liquid oils about 1 billion. Edible shortenings total another 1.5 billion. Edible lard which once had the entire shortening field to itself lost this usage to the hydrogenated cottonseed and soya products—best known as Crisco and Spry. In recent years lard, processed to reduce its typical flavor and improve other properties, has made a moderate comeback as a shortening.

The other 3 billion pounds of fatty oils are of the inedible grades. Soap still uses about 2 billion pounds—mostly inedible tallow and grease. Paints, varnishes and linoleum use those stocks known as drying oils totaling about 800 million. The balance, another 300 million, goes for miscellaneous uses such as special fatty acids, lubricating greases, printing inks, synthetic detergents, etc.

These data refer to pounds—neither barrels nor tons. One large petroleum refinery handles as great a weight of material as the entire fat and oil industry. In the latter a large processing unit in a large company plant might handle 10,000 lb./hr. and cost two to three million dollars. Many products, even in a large company, are manufactured on a much smaller scale than this. For example, a large soap plant makes about ten different formulas of kettle soap, using different percentages and grades of the various available fatty oils. From these ten bases many more differently finished products are turned out. While some of these bases are used only for small quantity items, at least four are considered large items. This demand for flexibility and variety makes the application of continuous processes rather involved and results in small savings relative to the old batch units.

Raw Material Costs

The next important part of the background is that of raw-material costs. The edible grades of oils will run 14 to 20 cents/lb.; drying oils about same. Many of these are interchangeable, at least in part, when subjected to further processing. Thus cottonseed and soybean oils compete for the margarine and shortening business along with edible lard. Soybean oil competes with linseed; linseed and dehydrated castor with tung oil for drying pur-

The author of the accompanying article, a Cornell chemical engineering graduate with a doctorate from New York University, is with the research and development department of the Colgate-Palmolive Co. As head of the soaps division Mr. Lawrence is responsible for the development of new soap and synthetic detergent bars. After graduating in 1941 he spent three years with Colgate-Palmolive before leaving to go with Carbide & Carbon Chemicals Corp. on the Manhattan Project. He returned to Colgate in 1946.

In this discussion of the fat and oil industry the author gives some interesting data on economics and product quality.

poses whenever the price differentials permit the necessary processing costs. Even these are subject to competition from synthetic resins of which glyceryl phthalate is the best known.

The inedible tallows and greases which form the backbone of the soap and industrial fatty acid industry should be selling at 8-9 cents/lb. to be in line with the above-named prices. Today, however, the large-scale replacement of soaps with petroleum-based synthetic detergents has cut off about 500 million pounds from fat sales. Furthermore, when synthetic detergents are made from fats, they are sold as trade-named products with only about one third as much active material as comparable soap products. Hence, the fats go further and less poundage is required. This has brought the tallow market down to about 4 cents/lb., a price which makes the large packing houses look around for other outlets. Since retail meat customers have only a limited tolerance for buying large quantities of fat with their roast beef, rendered tallow accumulates as a by-product. There is even a rumor (though unlikely) that one large packing concern has considered processing tallow to recover glycerine and then burning the fatty acids. Since glycerine sells at about 40 cents/lb., the fatty acids derived from 4-cent tallow are worth only a cent and a half. In any event, the hope for tonnage chemicals from fats derives from the currently depressed tallow market. With the resulting benefits to the nations' farmers as their goal, the Regional Laboratories of the Department of Agriculture are searching for economically sound outlets of fatty oils, including chemical uses. Though considerable progress is being made, research and development are slow processes.

Of the above prices only tallow and grease can be considered cheap as a starting point for tonnage chemicals. Furthermore the industry as presently constituted is not set up to exploit this kind of industrial chemical market. Examined from a distance the present industrial setup can be considered as buying fats by the tank car and selling them, after some processing, in small packages to private consumers. Being organized on this basis, raw-material costs amount to about 80% of manufacturing costs. To sell new chemical engineering processes to the existing industry, the new process must offer one of the following advantages:

1. Higher yield, lower losses from currently used raw materials.

2. Ability to use cheaper grades of raw materials.

3. A better quality product, which will promote sales.

A saving in operating labor or utilities alone is seldom sufficient to justify gambling on a new untried process, much less if old-style processing equipment is still serviceable.

Conversion Processes

A brief outline of the processing by which fatty oils are converted into useful products will serve to define terms before going into a more detailed description of the newer processing methods.

All fatty oils have to be recovered from the fibrous tissue in which they occur in nature. Those which are normally liquid are mechanically pressed from the tissue and may be completely recovered by solvent extraction. This applies in general to the vegetable oils. Those which are normally solids are usually heat rendered, such as tallow and grease. The quality of the recovered fatty oil will be largely determined at this point. If the seeds, beans or fatty tissue, are allowed to oxidize and rot, if they contain contaminants such as flesh and blood in animal fats, or, if they are overheated, the recovered oil will be permanently affected. As a general rule the best quality final products can be made only from best quality original oil. Fractions of a per cent of oxidized fat or contaminants are never completely removed. Low-grade fats can be markedly improved as to color and odor but will remain inferior to their better quality brothers properly processed.

For the better quality uses, whether as edible oils, drying oils or soap, the fat stocks are subjected to refining with alkali and to bleaching with activated earth or carbon. Alkali refining reduces the free fatty acid normally in the crude oil but, even more important, the soap slurry formed carries with it proteins, phosphatides, gums and color bodies. Some of the impurities removed by this treatment are known; others, it will be noted, are described in general terms. The soap stock, also called refining foots, obtained is usually dark in color, of bad odor, and poor stability. From edible-oil processing it is usually sold to soap makers and fatty-acid processors. Bleaching of the refined oil then reduces the color still further and filters out any entrained soap stock.

For edible purposes the oil—usually cottonseed or soya—is either hydrogenated lightly to improve its stability on aging (as for salad oils) or more fully to convert it into a more solid fat suitable for shortening or margarine. Hydrogenation, at first glance, involves the saturation of double bonds; actually a simultaneous isomerization of the naturally occurring *cis* configuration to the higher melting *trans* form occurs at the same time. The desirable properties of proper plasticity of the solid and melting point depend on the control of these two simultaneous reactions. The oil is then subjected to steam stripping under vacuum to remove volatile impurities, which contribute to off-odors and tastes.

For drying oil, blends of oils and resins are used with the selection dependent on both price and the use for which the final product is intended. From soybean oil a more highly unsaturated and hence faster drying fraction can be separated and the less satisfactory fraction utilized for other uses. This faster drying fraction competes with linseed oil, which in turn can be subjected to fractionation processes to yield a tung-oil competitor. Castor oil in which the fatty fraction contains a hydroxy acid—ricinoleic—is dehydrated to give another tung-oil competitor. Dependent on their lower price, fish oils and tall oil (a by-product from the paper industry) can be used in part.

For soap uses tallow and cocoanut oil are the most common fats. Usually the color is reduced by refining and bleaching or by extraction with liquid propane—the Solexol process. Then the fats are reacted with alkali to form soaps and release glycerine as a by-product. The glycerine is extracted by an alkaline brine, which is sufficiently concentrated to salt out the soap as an insoluble curd. Dilution of the curd with water converts it into a pumpable liquid called neat soap. Alternatively the fats are hydrolyzed with water to yield fatty acids and aqueous glycerine. Since the acids have less than one-third the molecular weight of the original fat-glycerine ester, they can be distilled and hence improved in color. This constitutes the major advantage of the fatty-acid process for soap makers. A simple neutralization of the distilled acids with aqueous caustic soda is used to give a molten soap essentially identical to neat kettle soap.

For other industrial uses the fatty acids may be separated by fractional crystallization. The solid acids are referred to as commercial stearic; the liquid as red oil or commercial oleic. The former has a ready market; the red oil however is more difficult to move except at much lower prices. This illustrates one of the major problems facing the dream of "tailor-made" soaps, which was the center of such speculation and hope about ten years ago. At that time there was considerable discussion on how soaps should be made by the optimum blending of the individual fatty acids previously separated from the naturally occurring mixtures. It is easy enough to separate fats into their component acids by crystallization and fractional distilla-

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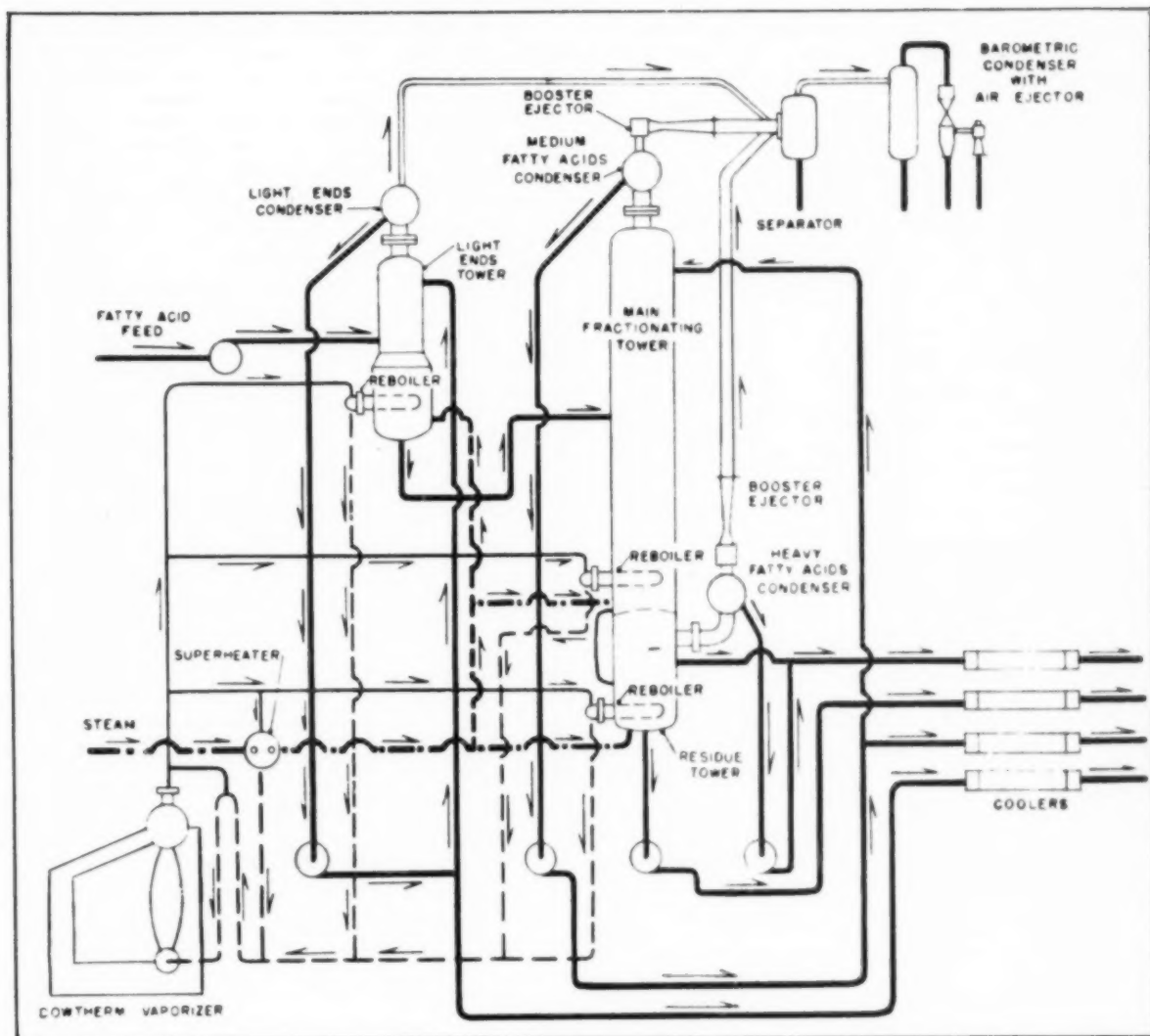
Fig. 1. Fractional distillation of fatty acids.

tion. It is also easy to point to one or two fractions and show how valuable they would be. However, the less desirable fractions won't just go away. Usually half of the fractions have no particular virtues, and with high-cost starting material this unpleasant fact looms large. As a way out of this dilemma one company is getting ready for large-scale oxidation of oleic acid to yield the more valuable nine carbon atom mono- and dicarboxylic acids. Fractional distillation of cocoanut fatty acids to strip out the eight and ten carbon atom acids is apparently economical because the light ends are not wanted in soap and are wanted for reduction to the fatty alcohols prior to conversion to dioctylphthalate-type plasticizers.

The use of fats as starting materials for large-scale synthetic detergent manufacture is dependent on converting the terminal carboxylic acid group into a sulfate or sulfonate. The sodium salts of the sulfates and sulfonates perform well in hard water, whereas the carboxylic acid (soap) forms insoluble lime salts. One method is to reduce the carboxyl to an alcohol either by sodium reduction or high-pressure hydrogenation. The alcohol can then be treated with oleum to give an alkyl sulfate. Another method is to esterify the carboxyl with a polyalcohol sulfate which converts the acid to an ester and leaves a terminal sulfate. Alternately the carboxyl can be converted to the more reactive acid chloride and, by reaction with sulfonated amines, converted into amides with terminal sulfonates. There is also active interest in so-called nonionic detergents where the carboxyl is converted into an amide or ester, leaving multiple hydroxyl groups to give the hydrophobic-hydrophilic balance to the molecule. Unfortunately in most cases it is expensive cocoanut-oil acids which give the best performance and these face stiff competition from the petroleum-based sulfonated alkyl benzenes.

Distillation Operation

From an engineering viewpoint the fat and oil industry is typical of those intermediate-sized chemical operations which started the transition from batch to continuous operations only within the last twenty years. As has been so commonly the case, the successful operations in the petroleum industry were used as a guide and modified to fit the peculiar properties of the materials handled. Once the 18-8 stainless steels

were developed in the late 1920's and early 30's, a major block to high-temperature processing was removed. This opened the way to the development of continuous methods for the manufacturing and processing of fatty acids and the preservation of fatty-oil quality.

Distillation operations which had made use of direct-fired iron pot stills with copper condensers now use Dowtherm vapor heating and bubble-cap towers (Fig. 1). These old stills produced large quantities of polymerized material or pitch and poor-quality acid containing dissolved copper—a prooxidation catalyst. Even under 5-25 mm. Hg abs. the difference between the boiling point and the decomposition temperature range is so narrow that the close control provided by Dowtherm is a must. As a rule of thumb 300°C. (575°F.) may be considered as the maximum permissible temperature; 280° C. (536° F.) is preferable. Decomposition occurs below this but can be tolerated. The equilibrium boiling point for eighteen carbon-atom acids at 20 mm. Hg abs. is 242°C.(13). Superheated steam is usually used to reduce the partial pressure still further and to provide agitation. Simple distillation, where all volatile products are taken overhead and dark, nonvolatile material is the only bottom product, is now continuous. Bubble-cap columns with 2 mm. Hg or less pressure drop per tray are becoming fairly common. Reboilers are designed with low holdup

to keep decomposition at a minimum. One manufacturer makes bubble-cap columns with hollow trays, each of which is Dowtherm heated, to provide vaporization at the lowest possible pressure. One unit has been built with Koch Kascade trays and is operating successfully (2).

In addition to the simple and fractional distillation of acids, stripping operations are carried out to remove volatile odor and flavor constituents from nonvolatile fatty oils (Fig. 2). Using large volumes of steam as well as good vacuum, deodorization is handled both in batch vessels and continuous columns (3, 17). Since any free fatty acids in the feed stock will steam-distill out with the odor and flavor bodies, the method is economically applied only to alkali refined oils—usually of edible grade. Special precautions such as hot tops are often used to prevent condensation of stripped impurities.

Fractional Crystallization

Another operation which has been brought up to date by borrowing petroleum techniques is fractional crystallization. The older method involved first chilling fats or fatty acids, then wrapping the solid fat stock in cloth bags in which the acids are partially heated and pressed to separate the mother liquor from the higher melting constituents (3). Similar to solvent dewaxing, the newer installations now utilize continuous chilling of a fat-solvent mixture with subsequent filtration on a continuous drum filter (5, 9)

(see Fig. 3). Both aqueous alcohol and liquid hydrocarbons including propane have been used. The installation includes the usual elaborate solvent-recovery equipment. One of the major problems in the application of this operation is that of obtaining good filterable crystals which can be easily washed free of the mother liquor.

Solvent Extraction

Extraction with solvents as applied in this industry takes many forms, some ranging into the field of "art." The most straightforward application is that of separating fatty glycerides according to their degree of unsaturation by countercurrent liquid-liquid extraction. The unsaturated acids are more polar than the straight-chain saturated acids. Using a polar solvent such as furfural (7), the highly unsaturated fractions appear in the extract. By use of countercurrent columns with reflux and with nonpolar naphtha as a second solvent, practical separations can be achieved. This process is primarily of interest in the paint and varnish field where the more unsaturated portion of soybean oil makes a linseed substitute and that from linseed makes a tung-oil substitute. Although the fatty acids themselves would be easier to separate, the glyceride esters are desired for drying-oil purposes. Liquid propane can also be used for this separation, but is of greater interest for decolorization (6, 12). By using the propane slightly below its critical temperature, the oxidized fats and the color bodies are less soluble than the simpler straight chains and can be separated from the good oil or fatty acids as a separate phase. This
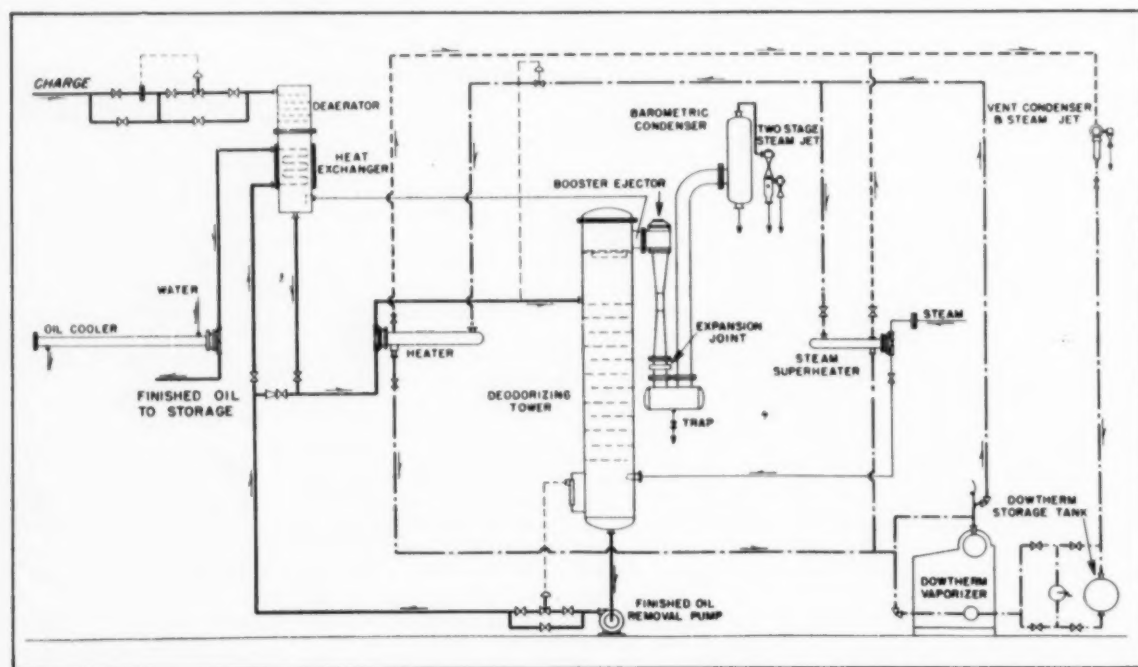
Fig. 2. Deodorization of edible oils.
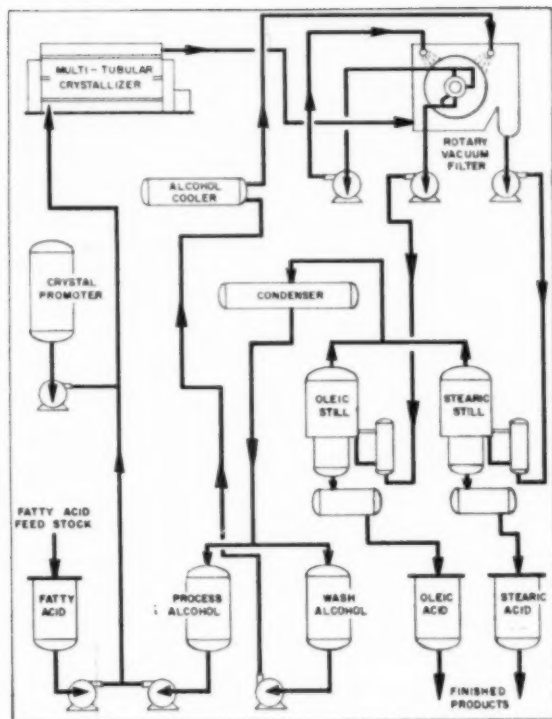
Fig. 3. Emersol process—fractional crystallization
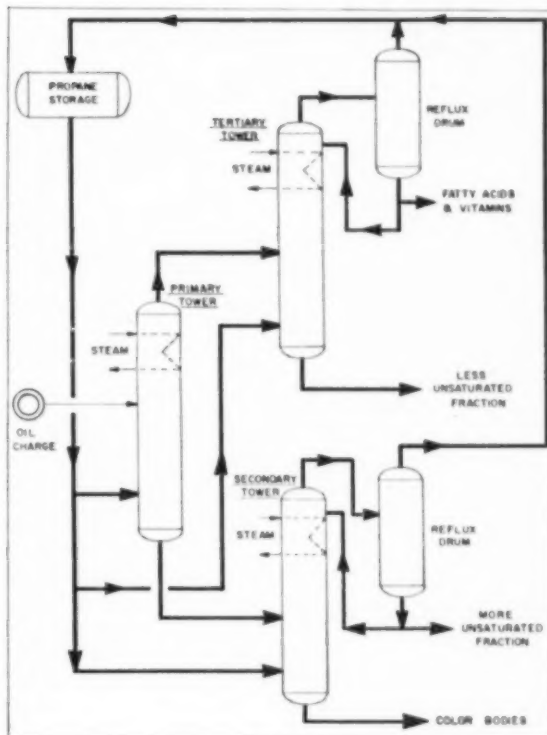
Fig. 4. Solexol process—liquid-liquid extraction with propane.
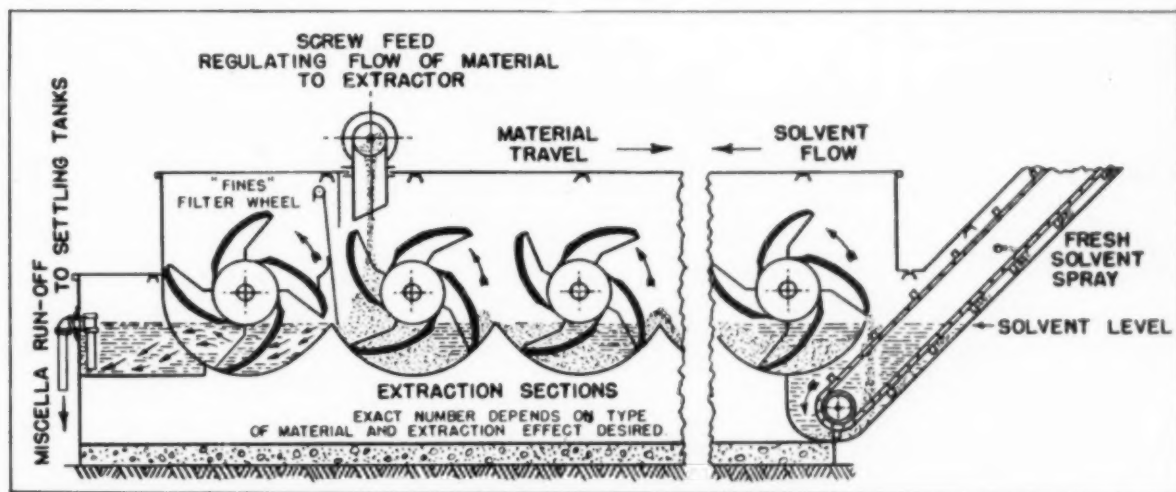
Fig. 5. Kennedy extractor for oil from cottonseed flakes.
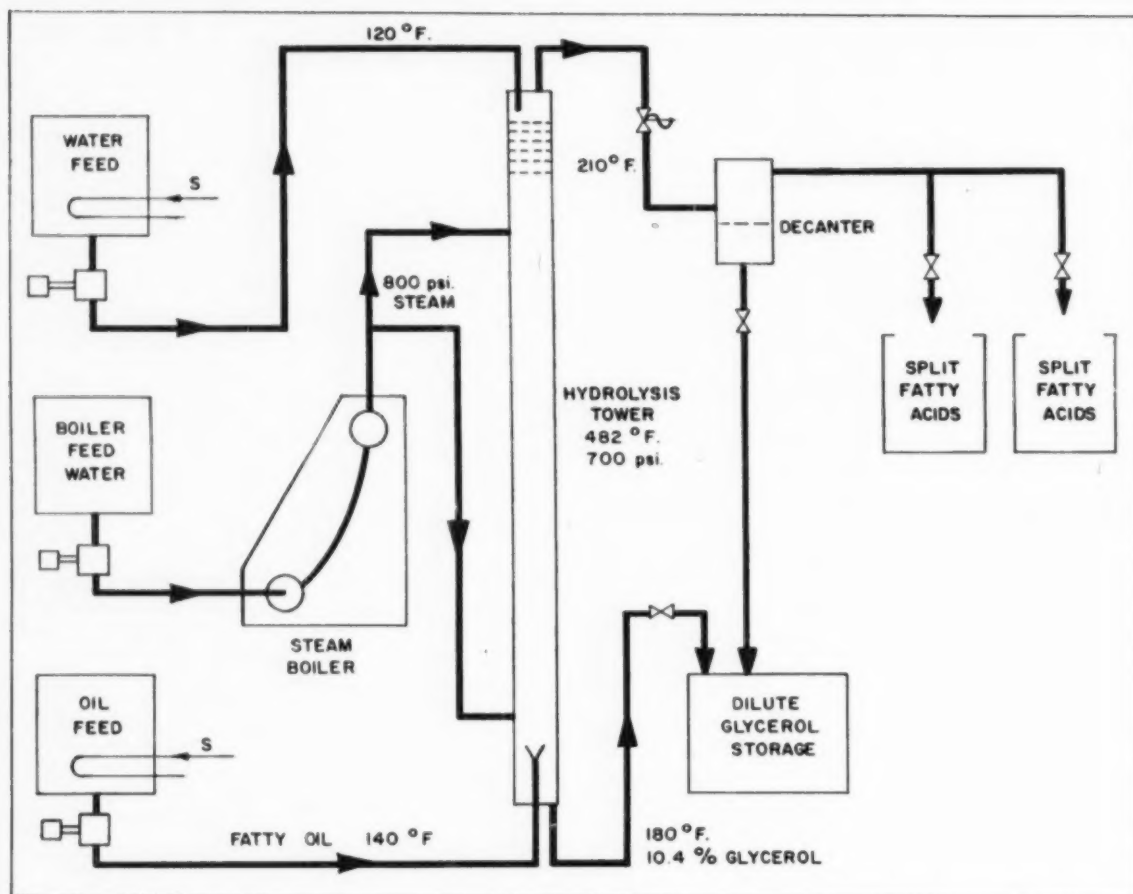
Fig. 6. Continuous hydrolysis of fats to fatty acids.
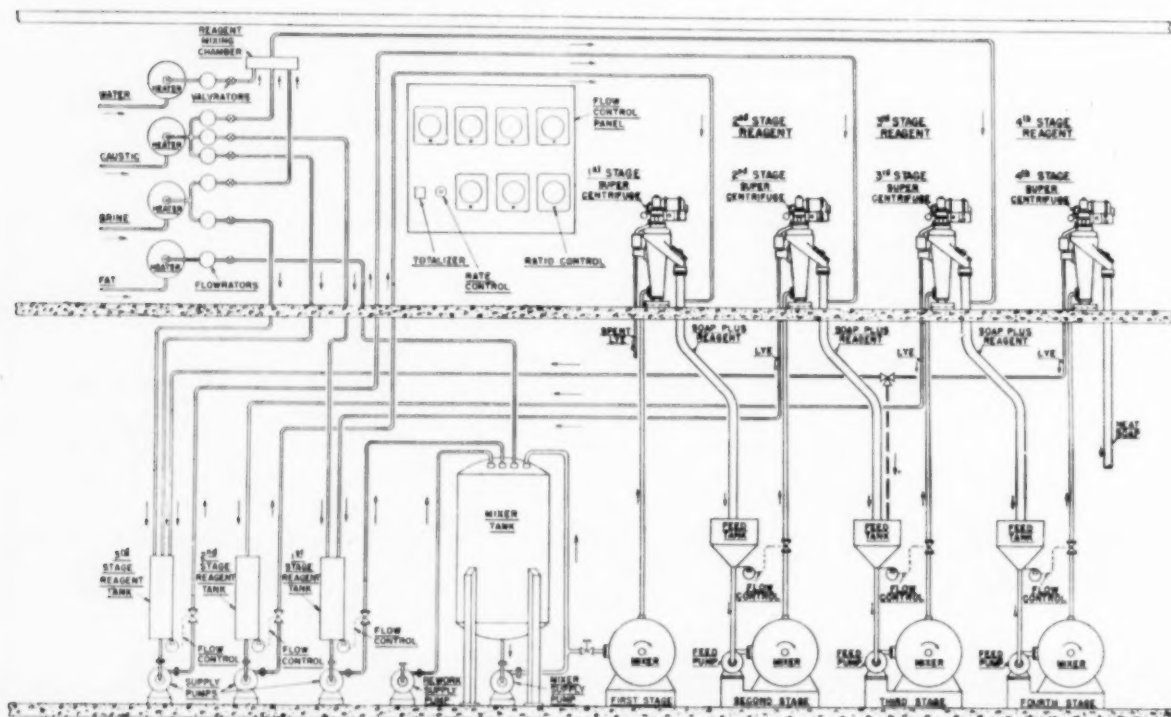
Fig. 7. Sharples process—continuous soap making.

Courtesy of The Sharples Corp.

is M. W. Kellogg's Solexol process of decolorization (Fig. 4).

The principal application of solvent extraction, however, is in the winning of vegetable oils from their seeds (3). As applied on a large scale to cottonseeds and soybeans, it is the central step of a multiple-step process. The seeds are cleaned, hulled, rolled into flakes, cooked to breakdown the cell walls and coagulate proteins, and then extracted with hexane or a similar petroleum fraction. Many of the plants are continuous with elaborate provisions for moving the solids flakes countercurrent to the solvent stream as shown in Figure 5. (11). Some plants press the seeds first and recover part of the oil mechanically before extraction. Then again other plants don't use solvent extraction at all but carry out all the recovery by pressing. Not only does the over-all problem include that of efficiently extracting oil from a solid but also is attended by a multitude of quality problems relating to the toxicity of the solid cake which is sold for animal feed, and to the color and refining losses in further processing the oil. These quality factors in turn are related to the flake-cooking operation as well as the subsequent extraction. The economics of the operation requires the production of a salable animal feed as well as recovery of good oil.

Many of the operations carried out in the fat and oil industry are more complex from an engineering viewpoint than the single unit operations considered so far. Combined reactions and extraction are common characteristics. In the modern continuous fat-splitting process (1), fat and water are fed into a countercurrent tower (Fig. 6). At about 450° F.-560° F. even without catalysts, the fats break down into fatty acids and glycerine. The fats being the lighter phase are fed to the bottom and leave at the top of the tower. Water fed to the top extracts the glycerine released as a reaction product of the hydrolysis of the glyceride esters. Removal of the glycerine from the oil phase and its replacement by water permits the reaction to go to completion. Catalysts increase the reaction rate but the extraction rate controls the final yield. The engineering analysis of this operation is further complicated by the three-step reaction which occurs as the triglyceride ester hydrolyzes stepwise through di- and monoesters to free acid and glycerine. Relative to the older Twitchell process the reaction can be carried nearer to completion with consequent economical benefits in yield of distillable acids and recoverable glycerine.

Soap making also involves extraction of liberated glycerine resulting from decomposition of the fat. In this case the fatty acids are tied up at the sodium soaps which are salted out of the solution as a curd by the strong electrolyte; the glycerine is extracted into the aqueous phase (15). In batch kettle operation the free glycerine is extracted by repeated washing with a salt lye using open steam for agitation. In a large production operation the washing is carried out batch countercurrent with the washing lye being pumped from one kettle to another. There are also a couple of continuous soap processes. Sharples Corp. has one (14) in which the washing is carried out countercurrently in a series of mixing stages followed by centrifuges to separate the two phases (Fig. 7). A French process uses a tower with separate sections provided with mixing and settling zones so that a countercurrent operation is achieved (10).

More details on soap making can be used to illustrate why the fatty-oil industry is generally plagued by a lack of firm fundamental data which results in vague engineering.

For soap the principal feed stock—the fat—is a multicomponent mixture containing a number of fatty acids esterified with glycerine. Usually more than one fat is used so that five to eight different acids are usually present in appreciable quantities. The fat is reacted with a mixture of caustic soda and salt with sufficient total electrolyte to keep the sodium soaps grained out as soft curds. Depending on the salt concentration, the curds may be large and soft or small and hard or tight-grained. Better mixing and washing are obtained with soft curds but sufficient salt must be present to prevent the soap from going into solution. This necessary salt concentration is different for different fatty-acid soaps. After the saponification is complete, the curd soap is washed, not only to remove glycerine but also to reduce the free alkali. Since the soap must be kept grained, the wash lye used in the last stages is relatively higher in salt and lower in caustic than the first wash lye. Finally with the glycerine removed, it is necessary to finish the soap in such a way that the alkali and salt are reduced and the soap left in a pumpable condition. First, water is added, reducing the salt concentration till the soap is almost ready to go into solution. At this point a so-called half-finish lye is removed and with it much of the residual salt and caustic. Then more water is added until the soap curd is large and only traces of a separate lye layer can be noticed.

The mixture then settles slowly into an upper layer of "neat" soap containing only about 30% water with only 0.5% salt and less than 0.25% free alkali and a lower layer of watery soap called "nigre," which contains only about 35% soap, considerable salt and alkali, and the soaps of some of the darker oxidized fatty acids. Part of the lower layer is degraded to a darker

product to avoid color build-up and the balance is recycled to another kettle.

The above-related phenomena must be considered in designing a continuous process such as the Sharples unit which includes continuous nigre separation. Economic considerations also dictate the use of a minimum quantity of water since added water forms a load on the glycerine house evaporator and economy in caustic soda requires that the excess alkali in the lyes to the glycerine-recovery process also be kept low.

Fatty Alcohol Sulfates

The most important commercial production of chemical fat derivatives is that of fat-based synthetic detergents, principally the fatty alcohol sulfates. Fatty esters are reduced to fatty alcohols by either high-pressure hydrogenation (16) or metallic sodium (8). The alcohols are then treated with oleum to yield the alcohol sulfates which on neutralization with alkali give the sodium salts. Both cocoanut oil and tallow are now used as starting stocks for the products. Though sodium reduction is the simplest approach, it brings with it an economic problem for such reduction requires a minimum of 4 moles of sodium which ultimately ends up as sodium hydroxide. If fatty glycerides are used as the starting ester, then the caustic will contain glycerine. Presumably this has been used in the past for soap-boiling operations in which the glycerine is readily recovered. Today, with declining soap sales, this outlet is becoming restricted (4). Undoubtedly this problem can be overcome by first converting the glycerides to esters of some lower alcohol and recovering the glycerine at that point. However this is another processing step and is presumably one reason for the renewed interest in high-pressure hydrogenation.

One more operation can be mentioned to illustrate the scope of engineering in the industry.

The well-known packaged synthetic detergents and packaged soaps such as Fab, Tide, Surf, Super Suds, Rinso, and Duz are spray-dried beads. They will run from 10 to 100 mesh in sieve size with the bulk of the sample at 40-60 mesh. This large size particle is free flowing and relatively low in dust. To produce such products a slurry is made up by mixing the neutralized synthetic detergent or soap base with added inorganic salts such as phosphates and silicates and with other minor ingredients. This slurry at 60-70% solids is pumped to a set of atomizing nozzles in the top of a tower where the resulting droplets are dried by hot air (Fig. 8). The towers are of the order of 20 ft. in diam. and 60-80 ft. high and have a capacity of 10,000 to 15,000 lb./hr. The air flow may be
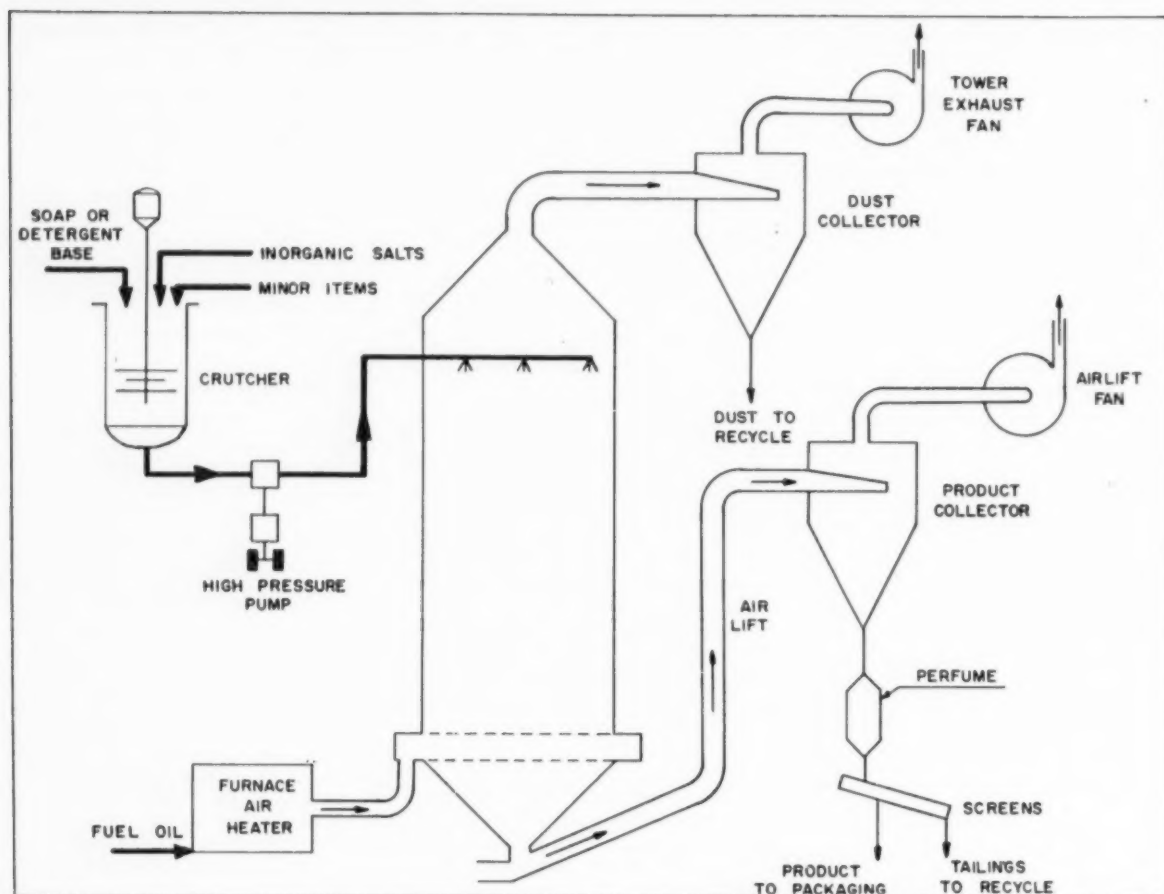
Fig. 8. Spray drying for soaps and detergents.

either concurrent or countercurrent. The dried beads are separated from air stream, cooled, perfumed, screened to remove tailings and packaged. To avoid being a public nuisance fine dust is removed from the tower air before exhausting to the atmosphere. Material which is too coarse or too fine is recycled to the slurry mixers. Particle-size distribution, fines, apparent density, moisture, and decomposition of the expensive polyphosphates all require consideration, and are controllable in part by balancing the drying air temperature, air flow rate, air flow pattern, size and design of spray nozzles, slurry concentration, and slurry temperature.

Summary

By selecting a few of the more interesting applications as illustrations, an outline has been attempted of chemical engineering in the fat and oil industry. The author has tried to show how the peculiar economics of the industry gets in the way of a lot of good engineering. Naturally there are many day-to-day problems in fluid flow and heat transfer but even these are not straightforward. Sizing of fat and oil pipe lines may be easy, but 60% solids slurries are troublesome. The latter are called liquids by courtesy

only. The fundamental engineering necessary for design of heat exchangers and mixing vessels for non-Newtonian fluids is not readily available. Extracting cottonseed oil from flakes and drying soap beads requires knowledge of diffusion mechanisms within the solid. In the latter case even securing representative samples from various points within a spray-drying tower becomes a knotty problem. The industry is slowly filling in the large vacant areas in physical property data and developing techniques for engineering research. However, the easiest way to size a soap line is still to pick up the 'phone and ask the foreman, "How big is the yellow soap line over to B-7 building?"

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History and Philosophy of Chemical Engineering Education

D. B. Keyes

Long interested in chemical engineering education, one time head of the chemical engineering division of the University of Illinois, the author of this article, Donald B. Keyes, has studied its history and philosophy and has come up with some interesting data and stimulating views of the pioneering days. Here is the story of progress since the early nineteen hundreds. Dr. Keyes is now New York representative for Arthur D. Little, Inc., industrial research and engineering organization of Cambridge, Mass. He has been also associated with the U. S. Industrial Chemical Co., and with Heyden Chemical Corp.

The philosophy of chemical engineering education encompasses the development of curricula, courses, teachers, teaching methods, and even laboratories and other facilities. On the basis of this definition, our purpose is to trace the changes in the philosophy of chemical engineering education over the four main periods of growth in the United States: (1) from a few years before the end of the nineteenth century to the beginning of World War I; (2) between 1915 and 1925, the period in which quantitative principles were roughly stated; (3) from about 1925 to this country's entrance into World War II, years in which chemical engineering education saw its most remarkable growth; and (4) from the end of the war to the present time.

Although the American chemical industry had been developing in the nineteenth century, it was not until World War I forced the United States to create a synthetic organic chemical industry that the need for chemical engineering graduates became evident. After World War I the chemical industry in this country began to grow tremendously and continued to grow even faster during and after World War II. Today almost any graduate of a reputable chemical engineering curriculum can find challenging opportunities in our chemical industry.

History of Chemical Engineering Instruction

The Massachusetts Institute of Technology is credited with having organized, in 1888, the first curriculum in chemical engineering in this country. In 1894 the University of Illinois created a curriculum in applied chemistry and a separate department for that purpose, and at Tulane University the name of the department of chemistry was changed to chemistry and chemical engineering. The University of Michigan in 1898 established a curriculum in chemical engineering, and after the turn of the century many other colleges followed these examples. Unfortunately, however, the courses in chemical engineering were largely descriptive. Some interest was shown in chemical engineering equipment but seldom from a quantitative design standpoint.

In Europe comparable activities were getting underway. In England, George E. Davis lectured on chemical engineering in the Manchester Technical School as early as 1887 and in 1901 published the first handbook of chemical engineering. Although Davis had indicated the desirability of treating the subject quantitatively, most of his material was descriptive. E. Sorrel of France in 1893 wrote a book on distillation in which the quantitative side was stressed. E. Hausbrand of Germany published a similar book in the same year and followed it with another book in 1895 on chemical engineering from a quantitative standpoint.

In the early days of the American industry, most chemical experts working in the chemical industry were called industrial chemists, rather than chemical engineers. Their training was in chemistry, and few were in the engineering field. It was the graduate of the mechanical engineering curriculum who was most interested in the design of equipment for the chemical industry. The chief industrial problem was in adjusting a chemical reaction so that it would operate in standard equipment already designed and built by mechanical engineers.

The industrial chemist, with an excellent knowledge of chemistry but little training to solve the large-scale problems of the chemical industry, satisfied the educational world. The curriculum in chemical engineering fifty years ago embraced engineering and chemistry, with emphasis on the latter. There was little recognition that chemical engineering was not a mixture of the two fields, but a distinct branch of engineering. It was this attitude that prevented the growth of chemical engineering education in the early 1900's.

Who was the first chemical engineering department head? We don't know for certain, but "C.E.P." enlisted the aid of Professor T. K. Sherwood of M.I.T. in checking. The result was a picture of Professor Lewis M. Norton, sketched at right, who in the words of Sherwood "was a professor of chemistry here back in 1882-93 and who, according to Doc, (W. K. Lewis) was 'head of the course' when chemical engineering became a separate curriculum administered by the Chemistry Department. Doc thinks this makes Norton the first head of a chemical engineering curriculum in the world."

It should be remembered, moreover, that in these early days practically no synthetic organic chemical industry existed in this country. Rather it was in Germany that rapid strides were being made in the creation of new organic compounds. Most of the processes here came from Europe. Our endeavors were confined largely to heavy chemicals employing large-scale production and well-known chemical processes. New equipment, even of the larger type, was usually developed in Europe and brought over here, where it might be improved by experienced engineers.

Thus, a group of "practical" chemical engineers gradually emerged who had obtained their training through experience. As the quantitative principles of chemical engineering were not taught in the colleges, these men developed their own knowledge and methods. This knowledge was valuable, but was considered unpatentable and therefore secret, a philosophy that also contributed to the stultification of chemical engineering education.

A similar attitude prevailed at this time in Germany. The industrial chemists, who had done an excellent job in applying their knowledge to the synthesis of valuable organic chemicals, rose in the industry. Chemical engineering, in fact, played only a small part in the synthesis, largely because the end products were costly and were made in relatively small units. There was a tendency to belittle the engineering features of a synthetic organic process and to place greater emphasis on developing new processes and products.

After World War I, this attitude changed, particularly in America. American production methods demanded large units and low labor costs. Processes had to be made continuous. It was the American chemical engineer with his vision and daring that made these large-scale syntheses feasible and reduced the cost of the final product for universal use.

Modern Chemical Engineering Education in U. S.

The American Institute of Chemical Engineers was organized in 1908, but it was not until 1922 that its first official definition of chemical engineering was developed by the chairman of the Accrediting Committee, Arthur D. Little:

Chemical engineering, as distinguished from the aggregate number of subjects comprised in courses of that name, is not a composite of chemistry and mechanical and civil engineering, but itself a branch of engineering, the basis of which is those unit operations which in their proper sequence and coordination constitute a chemical process as conducted on the industrial scale.

An earlier report by Dr. Little and William H. Walker of M.I.T., directed to the corporation of M.I.T. in 1915, had clearly described this concept of the basic unit operations of chemical engineering.

Over the years several definitions have been advanced and the A. I. Ch. E. recently approved a description of chemical engineering and incorporated it in its Constitution:

. . . Chemical Engineering is the application of the principles of the physical sciences together with the principles of economics and human relations to fields that pertain directly to processes and process equipment in which matter is treated to effect a change in state, energy content, or composition.

Unit operations was the first real approach to the quantitative side of chemical engineering. With the exception of heat transfer and fluid flow, which are recognized today as the basis for these operations, unit operations such as distillation, evaporation, filtration, etc., had achieved recognition because well-known and specific equipment was used. It is interesting to note that most of these physical operations did not involve chemical reactions. The unit-operations concept immediately awakened interest in the quantitative aspects

of the subject. In 1916 Warren K. Lewis of M.I.T. gave four papers on unit operations at the annual meeting of the American Chemical Society. In 1923 appeared the first great treatise on the principles of chemical engineering, written by William H. Walker, W. K. Lewis, and W. H. McAdams, all of M.I.T. This was the start of a series of texts and reference books based largely on the unit operations of chemical engineering.

Interest was so intense that the American Institute of Chemical Engineers organized an Accrediting Committee to study chemical engineering education and to establish requirements. The committee by 1925 had started to accredit various curricula in chemical engineering throughout the United

the profit sheets reflected the value of this training.

Like all great ideas, the concept of unit operations has its faults. Much work has been and is being done on empirical relations between variables within a unit operation. Concepts that were justifiable from the standpoint of pedagogy have been extended beyond their field of usefulness. For example, the famous two-film theory where transfer takes place between a gas and a liquid has been a valuable concept, but it has little point, when it is applied where no film exists, such as in the formation and breaking up of bubbles in a fractionating column.

Modern Trends

Since chemical engineering is mainly a study of the control of chemical re-

courses year in and year out; they must constantly change and improve.

For the present, the usefulness of the chemical engineering graduate to industry can be improved by adding to his curriculum courses in the fundamentals of economics and specifically their application to the chemical industry. This subject has been added only recently to our chemical engineering curriculum, not because of a lack of interest but because of unfamiliarity with the subject. It is not a subject that can be reduced to a few simple laws, or perhaps we should say that the laws are simple but the application is complicated.

Economic Evaluation and Appraisal

Most of the older men in the chemical industry spend more and more time

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William H. Walker, who with A. D. Little, developed the concept of unit operations. Above is taken from the 1904 Technique, M.I.T. Student Yearbook. It was about this time that Professor Walker began to transform the curriculum from one of industrial chemistry to one of chemical engineering.

States. The list of accredited curricula has since grown from fourteen in 1925 to seventy-seven in 1953.

The Intermediate Period

After the publication of Walker, Lewis and McAdam's text in 1923, W. L. Badger and W. L. McCabe of the University of Michigan published their "Elements of Chemical Engineering," in 1931, and several monographs on unit operations were published.

Basic chemical engineering became an important subject for study and experimentation especially in the large industrial research laboratories. This development, in turn, increased the interest of professors of chemical engineering; the curriculum became more and more popular; more and more young men trained in unit operations were added to the university staffs; and the teaching of chemical engineering from the quantitative standpoint was greatly improved. This attitude was well received by the chemical industry. Pilot-plant design became more scientific, and

actions on a large scale in order to produce high yields at reasonable costs, a tremendous amount of fundamental work especially in physics remains to be done before chemical engineering education can advance. Much more must be known about the transfer of both energy and material in gaseous, liquid, and solid media. Knowledge of applied chemical kinetics and reactions at interfaces must be greatly extended before we have a real basis for reactor design.

Despite these gaps in knowledge, the chemical industry is constantly growing; if it did not, it would eventually die for there is no such thing as a stable chemical industry. One cannot expect a profit on a single process and product to be continuous no matter how efficient the process or how useful the product. Future developments will always outmode the process and possibly the product. It is this philosophy that underlies the complexity of the chemical industry and, in turn, denies the chemical engineering professor a fixed curriculum. He cannot teach the same

evaluating the results of research and development. Sooner or later all chemical engineers, young or old, must learn to combine technology and economics in order to appraise and evaluate results.

Four important questions should be answered in an evaluation of an industrial development:

What is the total cost, including the construction of the first commercial unit, and sales development if it is a new product; what is the probable profit per year on the entire investment; what is the predicted length of time that this probable profit will be maintained; and how does the new development fit in with the present activities of the company?

The accompanying Table A reveals that chemical engineering cannot be separated from industrial economics. However, it is evident that basic knowledge of chemistry and physics together with mathematics and general application of science to the chemical industry is the paramount goal of a four-year curriculum. In the light of conflicting

Table A.—Outline of the Appraisal of an Industrial Process Development

(Capital Cost, Probable Profit, and Length of Life)

I. RAW MATERIALS	II. PROCESS OR OPERATION	III. PRODUCT (Old and New, Including By-products)
A. Past, present and future cost	A. Chemical processes	A. Character of the product
B. Extent and adequacy of present and future source	1. Equilibrium (static or dynamic)	1. Chemical properties
1. Number of producers	a. Yields	2. Physical properties
2. Location of source	b. Conversions	3. Specifications and impurities
3. Collection and transportation	c. Material balances	4. Containers or package
4. Seasonal production	d. Energy balances	5. Storage
5. Waste material	2. Rates (time)	6. Safety factors
C. Specifications and character of impurities	3. Character of equipment	B. Market (past, present and future use)
D. Container or package	4. Labor requirements	1. Uses
E. Storage	5. Power requirements	2. Capacity
F. Patents	B. Physical operations (Similar to above)	3. Price range
1. Manufacture	C. Production rate (optimum)	C. Patents
2. Use	D. Patents (manufacture)	1. Product patents
G. Legal requirements	E. Legal production matters	2. Use patents
H. Tax, tariff, etc.	F. Safety factors	D. Trade marks
I. Safety factors	G. Capital cost	E. Legal requirements
J. Possible future developments	H. Operation cost	F. Tax, tariff, etc.
	I. Possible future developments	G. Sales service required
		H. Advertising
		I. Character of the customers
		1. Number
		2. Location
		3. Size
		4. Length of life
		5. Trade agreements
		J. Competitive products
		K. Character of competitors (same as for customers)
		L. Possible future developments

NOTE: Factors to be considered when evaluating a patent:
1. Extent of coverage by the claims
2. Exactness and completeness of the specifiations
3. Validation by a court

theories, the question arises as to how many subjects of a technical economic nature should be included in a chemical engineering curriculum.

Curriculum and Courses

At first a large variety of chemistry was included in all chemical engineering curricula. It soon became evident, however, that more quantitative chemistry and fewer descriptive courses were needed. The importance of physical chemistry was thus established years ago. On the other hand, analytical chemistry, wherever it had to do with empirical methods and specific techniques, has slowly disappeared. To a certain extent, its place has been taken not only by better and more extensive courses in physical chemistry but also recently by courses in instrumental analysis. These courses deal with the underlying physical principles and are not truly descriptive.

Organic chemistry, because of the importance of the modern synthetic organic chemical industry, has become popular in recent years as a fundamental course. This is especially true of laboratory courses devoted to the analysis of organic unknowns. Their importance is not that the student learns how to analyze unknowns but that he is forced to understand the basic principles of

organic chemistry. Furthermore, the student develops self-reliance; the laboratory instructor is not permitted to do his thinking for him.

Qualitative inorganic chemistry, on the other hand, is fast disappearing from the curriculum. Strictly speaking, it is a graduate course and is not qualitative analysis but a form of semiquantitative analysis. Such a course requires considerable background knowledge. Courses in inorganic synthesis are taking the place of these particular courses in the freshman year, and quantitative principles of chemistry are also being put in the freshman course. Another significant trend is that more and more courses in thermodynamics are being given by chemical engineering professors.

The importance of sound courses in physical chemistry has been obvious for many years. Besides thermodynamics, the professor of physical chemistry has been teaching courses in chemical kinetics. Experience has shown that the student benefits if courses in applied chemical kinetics are given by a professor in chemical engineering, who is more likely to understand industrial problems. Considerable discussion has taken place over the years on the value of laboratory courses in physical chemistry. The argument against them seems to be the excessive time consumed.

Courses in mechanical and electrical engineering were popular in the chemical curriculum some years ago, but it is doubtful that they are needed in the crowded curriculum of today.

As far as the more specialized engineering subjects such as mining, ceramic, petroleum, automotive, and aeronautical engineering are concerned, it is unlikely that they have much place in an undergraduate chemical engineering curriculum. In recent years there has been some argument as to the advisability of teaching metallurgy and metallurgical engineering to chemical engineering students. Metallurgical engineering is, strictly speaking, a branch of chemical engineering but need not be required.

Less debatable is the inclusion of fundamental courses in physics. Often included with physics today are required courses in theoretical and applied mechanics and kinetics.

All professional curricula, too, should have courses in mathematics. The primary difficulty that has been encountered in the chemical engineering curriculum is that courses in higher mathematics, such as calculus and differential equations, are taught by the mathematics department, whose interest generally lies in theory and whose knowledge of chemical engineering is limited. On the other hand, if a practical course in the use of differential equations is taught to chemical engineering students, it is obvious that it must be taught late in the program when the student is familiar with mathematical problems in his field.

In early days all curricula in chemical engineering included surveying and machine and wood shop work. These courses have largely been eliminated because the student spends too much time and energy learning specific facts and techniques for which he has little use in industry.

Many educators favor mechanical drawing in chemical engineering curricula. Industrial practice seldom requires skill in this subject, but a working knowledge is helpful. The chemical engineer may not make mechanical drawings, but he does make free-hand sketches, especially for reports and presentations of his own ideas.

Today our universities are frustrated by the fact that the high school product is seldom able to use English adequately. Present belief is that English can be learned only by constant guidance. The student should practice good writing and speaking habits in every course that requires a written or oral report. One university requires freshmen in chemical engineering to enter a theme-writing course. When they have had three themes accepted, they are allowed to

leave the course, but if at any time in college they submit a poorly written report they go back into the course and must produce three more satisfactory themes. This form of training is having a satisfactory effect. Another college employs two professors from the English department to correct chemical engineering reports.

It has been customary to require a foreign language, French or German, in the chemical engineering curriculum. Experience shows that a student can be taught to translate technical literature in less time if the course is designed for this purpose.

Many schools introduce chemical engineering early in the curriculum, in the sophomore or even the freshman year. Most students, however, can do better in these courses once they have learned fundamental physics and the quantitative principles of chemistry. Probably even elementary engineering cannot be adequately taught before the junior year. Most people agree that a five-year curriculum is fundamentally better than a four-year course, but financially it is not feasible.

On the subject matter of the chemical engineering courses themselves, it is obvious that unit operations and processes are essential. The old time industrial chemistry or chemical technology has been reduced to a cultural course, or the descriptive material is given in other chemical engineering courses. In recent years it has been found desirable to introduce industrial economics when describing industrial chemical processes. Recent articles on the subject are preferable to antiquated textbooks.

Chemical engineering is vitally concerned with material, energy, and economic balances. Studies of this character tend to bring together in a single problem many basic principles formerly taught in separate courses in chemistry, physics, mathematics, and chemical engineering. The importance of this viewpoint is clearly brought out in Chalmer G. Kirkbride's "Chemical Engineering Fundamentals," published in 1947.

In this respect, the student contest problem started by The American Institute of Chemical Engineers in 1932 has contributed much to the development of chemical engineering education in this country. These are practical problems devised by men in industry, which require the student to draw upon all his courses in science and engineering. Some schools consider these problems more satisfactory than actual laboratory research.

Most educators recognize that thesis work, especially for a master's degree, is at least theoretically desirable. Actual practice, however, has shown that thesis work is usually inefficient except in the

case of a student who is working for his doctor's degree and has presumably had some experience.

Laboratory work has received considerable attention over the years, but so far no one has developed a sufficient method of handling it. Years ago the attitude was that the student should find out a little about what he might expect in the chemical industry by operating semicommercial-scale industrial equipment. This idea has never been satisfactory, but the student at least learns not to lubricate a pump with sulfuric acid and to recognize the importance of pressure-release valves.

About forty years ago the first elaborate chemical engineering laboratories were installed in Columbia University. Students were permitted to prepare inorganic chemicals on a pilot-plant scale wherever the procedures were relatively simple and the process included only a few steps. A skilled mechanic and an experienced chemical engineer were always present not only to prevent breakdown of equipment, but also to safeguard the student. The student, however, designed the process and planned the work. These laboratories probably represented the best of those in existence at that date. This general idea became popular and other institutions followed the example, although seldom on the same scale. The course was primarily a preparation of inorganic chemicals in greater than test-tube quantities.

One school has operated over the years various stations in industry called practice schools. Here the student tests and evaluates processes and operation equipment under actual commercial conditions. This scheme has a distinct appeal in that it gives the student the real atmosphere of a chemical plant and permits him to study a process, product, or equipment and to make his own evaluation. To reproduce a similar laboratory within the university is economically out of the question, and it is probably impossible for many schools to follow the practice-school idea because industry must contribute much.

As years went by, and after the conception of unit operations was generally accepted, laboratories were built in order to test semiscale unit operation equipment. It was soon found that the two underlying subjects—fluid flow and heat transfer—required special equipment that could usually be made inexpensively in the college shops.

Standard chemical engineering equipment even on a reduced scale was not always satisfactory for instruction purposes. A fractionating column, for example, had to have much more efficient controls when it was on a small scale than it did on a large scale. Furthermore, for test purposes all sorts

of sampling and analytical equipment had to be devised. Today much of the elaborate equipment in our instructional laboratories was designed for research but was later found valuable for course work.

Additional Subjects

There is still a tendency to attract students by offering them specialized chemical engineering curricula, for example, in the fermentation industry. In this case, because of the popularity of the antibiotics and other biological products and because of the new complexities of the engineering involved, the student has a preconceived notion that he would like to go into this particular field. The graduate of such a curriculum is bound in the end to be less efficient than the boy who is more broadly trained. This does not mean that our colleges should not offer sound engineering courses encompassing the problems of the new biological industry. Such courses are necessary and worth while. The difficulty is to find time for such specialized courses except in the graduate school. Specialized courses in definite fields of chemical engineering such as a single unit operation, were at first thought desirable, but in time these too have become unpopular.

Because a university should be more than a training school, the appreciation of music, art, and literature cannot be ignored. Young people should be prepared not only for their profession but also for good citizenship. Furthermore, they should learn in their four-year college curriculum something about the valid pleasures of life. They should also, as preparation for their civic responsibilities, learn something of the fundamentals of government and of the social, economic, and political history of the rapidly shrinking world in which they live.

Faculty and Administration Policies

It has been stated that a college builds its reputation not on its facilities but on its staff. This dictum is borne out in the development of chemical engineering education in this country. Essentially, the instructor should not only know the subject but also have unbounded enthusiasm and interest in the development of chemical engineering and chemical engineers. It should be obvious that the chemical engineering faculty must have a direct contact with modern chemical industry. As do medical instructors, the members of the chemical engineering staff should continue to increase their knowledge of the subject by actual practice. The common method is to permit an instructor to do consulting work to the limit of his abilities. At the same time, it

is recognized that his primary work is educational and his prime obligation is to the university and its students. Moreover, it is possible that the primary reason the instructor is able to be a consultant for industry is because of the fundamental work that he and his students are doing at the university. In this connection, industry is often willing not only to provide funds, but also to supply special equipment and other facilities and to share in cooperative research with the university.

On the other hand, it has often been said that a professor of chemical engineering should have spent a period of his life in industrial research and development away from the university. In order to entice such men back into the academic fields, the university must permit them to obtain a living wage. Here again is a reason for engineering professors to engage in consulting work.

Instruction

In the past fifty years thousands of man-hours have been devoted to a discussion of how to teach chemical engineering and related subjects. No one seems to have found the solution. Professors who know their subject and have an interest in the student and a desire to promote chemical engineering education are not always successful. Perhaps great educators are born and not made. It is regrettable that most of us agree that they are few in number. Today in our huge educational "factories" economics dictates that the average student may have little contact with the great educator. Most of the student's work is with young graduate-student assistants.

The picture is further complicated by the fact that the chemical engineering curriculum is not primarily chemical engineering but is largely science, with only about 30 per cent of its courses taught by the chemical engineering faculty. It should be recognized that the other 70 per cent are equally important and their quality may at times be the determining factor as far as the success of the graduate is concerned.

Fortunately, bright young students have found one way out of the dilemma. For years they have gathered together in the evening for "bull" sessions. The brighter men invariably are able in such sessions not only to work out their assignments, but also to develop among themselves clear conceptions of the material presented in the lecture. It can be said that many of the successful graduates of the chemical engineering curricula throughout the country are self-educated men. It is now recognized that these so-called "self-

educated" men ask only that they be exposed to leaders in the academic world, that they be permitted occasionally to discuss with their professors subject matter that puzzles them, and that they be allowed to go to a school where they are surrounded by students with equal talent.

Statistics

In order to show the growth of chemical engineering education in the last half-century in this country, a few statistics are given. The first table shows the increased enrollment of chemical engineering students in U. S. colleges from 1910 to 1952. It also gives an indication for these years of the percentage of the total engineering students who were chemical engineers.
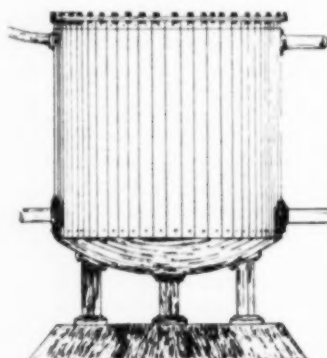
Table 1.—Student Enrollment in U. S. Colleges

YEAR	CHEMICAL ENGINEERING STUDENTS	PER CENT OF ALL ENGINEERING STUDENTS
1910	869	3.7
1920	5,743	....
1936	12,550	20.0
1946	17,392	14.0
1950	13,647	8.4
1952	12,704	9.1

Another table is given to show the effect of World War II on chemical engineering and all engineering students:

Table 2.—Graduates in Engineering From U. S. Colleges

YEAR	CHEMICAL ENGINEERS	TOTAL ENGINEERS
1936	1,705 (4th place)	8,088
1941	2,955 (3rd place)	12,455
1945 (end of W.W. II)	557 (2nd place)	2,321
1950	4,671 (4th place)	38,422
1952	2,743 (4th place)	30,286

It will be noticed that enrollment from 1936 to 1952 was interrupted by the war, when most of our engineering schools were practically shut down under the mistaken notion that there was no time for education.

Salaries of chemical engineering graduates have increased enormously in the past 37 years. The following table is an indication of what has happened:

Table 3.—Average Minimum Monthly Starting Salaries

YEAR	WITH B.S. DEGREE	WITH PH.D. DEGREE
1916	$100	$165
1951	$300	$500
1952	$360	$500+

These figures are only approximate. It should be remembered that the dollar has been devaluated and the cost of living greatly increased. The chemical engineering graduate today is probably not so well off financially as he was in 1916. Furthermore, present salaries may be for the present emergency only. Also, because of a low birth rate in the early thirties, the high schools are supplying fewer graduates than they were a few years ago.

What of the Future?

The future is predicted from the major trends of the past. Our process industry is growing enormously. The modern chemical engineering curriculum with its broad fundamental subject matter will undoubtedly be employed to train the majority of the men needed for this expansion.

Owing to this demand, it is expected that our instruction will improve, and it is hoped that fundamental research in chemical engineering will give our educators a better basis for this instruction. We shall undoubtedly have the funds, facilities and faculties to meet any challenge because the future of chemical engineering education in this country is assured.

The Ultimate

The highest aim in chemical engineering education, as in all education, is to train the student to think for himself. Any curriculum, any subject matter, or any type of pedagogy that will accomplish this result will justify its existence. . . . The history of the activities of our graduates has shown conclusively that our greatest teachers have been the men who have inspired their students with a desire for accomplishment in their field—a desire that can be fulfilled only by creative thought.*

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* J. Chem. Education, **10**, No. 12 (December, 1933).

Manufacture of Nitroglycerine
by the Biazzi Continuous Process

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Production of nitroglycerine by the Biazzi continuous process is described with special reference to the design of the equipment and operating experience at the first such plant erected in North America.

It is now 90 years since Nobel erected the first commercial plant for the manufacture of nitroglycerine. The plant consisted of a number of open porcelain or enameled cast-iron pots, containing a mixture of nitric and sulfuric acids to which glycerine was slowly added while the whole was stirred by hand with a glass rod. Since no cooling was provided, the quantity of glycerine nitrated in each pot was only one or two pounds. The nitration products were poured into water, whereupon the nitroglycerine formed an oily lower layer from which the dilute waste acid was separated by running off through a stop-cock in the dilution vessel. The nitroglycerine was washed with water until neutral.

Nobel's original plant was destroyed by a fatal explosion only two years after starting. Because of the well-known hazards associated with nitroglycerine the development of the manufacturing process has proceeded more slowly than might otherwise have been the case. Safety in operation took precedence over the mechanical and chemical efficiencies of the process.

Nevertheless the batch process has been developed to a high state of efficiency and individual plants have established safety records. Nitrators were increased in size and fitted with cooling coils and either mechanical- or air-agitation systems. Recovery of spent acid was made possible by the introduction of a separator vessel into which the agitated emulsion of nitroglycerine and spent acid might be run and allowed to stand while the former separated out. Washing of the crude nitroglycerine is done with water and sodium carbonate solution. The first or prewash is carried out in a separate vessel in the nitrator house, employing air agitation, and the final washing is done in a separate neutralizer house where the purified nitroglycerine is also stored.

The movement of nitroglycerine between the various steps of the process is frequently effected entirely by gravity fall and the plants are then constructed to take advantage of hilly terrain. In some batch plants there is a pulsometer after the prewash operation which offsets part of the loss of head.

Study and control of such factors as acid composition, nitrating temperature, and washing procedure have resulted in raising the yield of nitroglycerine in the batch process to about 95-96% of the theoretical yield.

Continuous nitration of glycerine was patented as early as 1878 (5), and a fully continuous manufacturing scheme was patented more than fifty years ago (2). However, largely because of concern about the safety of the innovations proposed, only two continuous processes have found any general acceptance— the one introduced by Schmid about 1927, described in the literature (1, 3, 4, 6), and the other by Biazzi in 1935. The Schmid process has operated satisfactorily in Europe but was never adopted in the United States or Canada.

In the selection of a process for nitroglycerine manufacture at the Calgary works, the alternatives were a continuous process or the standard batch process already in use at other explosives plants. The decision to install the Biazzi process was made primarily because it possessed the advantages of continuous operation and attention to safe operation. The much smaller quantity of nitroglycerine present at any moment in the process buildings also permitted a more compact arrangement, thus shortening lines and reducing the size of buildings. It has been standard practice at explosives plants to install duplicate nitroglycerine equipment as a stand-by in the event of loss of operating equipment. It was not judged necessary to provide duplicate Biazzi equipment for stand-by service at the Calgary plant.

Description of Biazzi Plant

The plant at Calgary is designed to produce 2,500 lb. of nitroglycerine/hr. With the exception of a few minor ac-
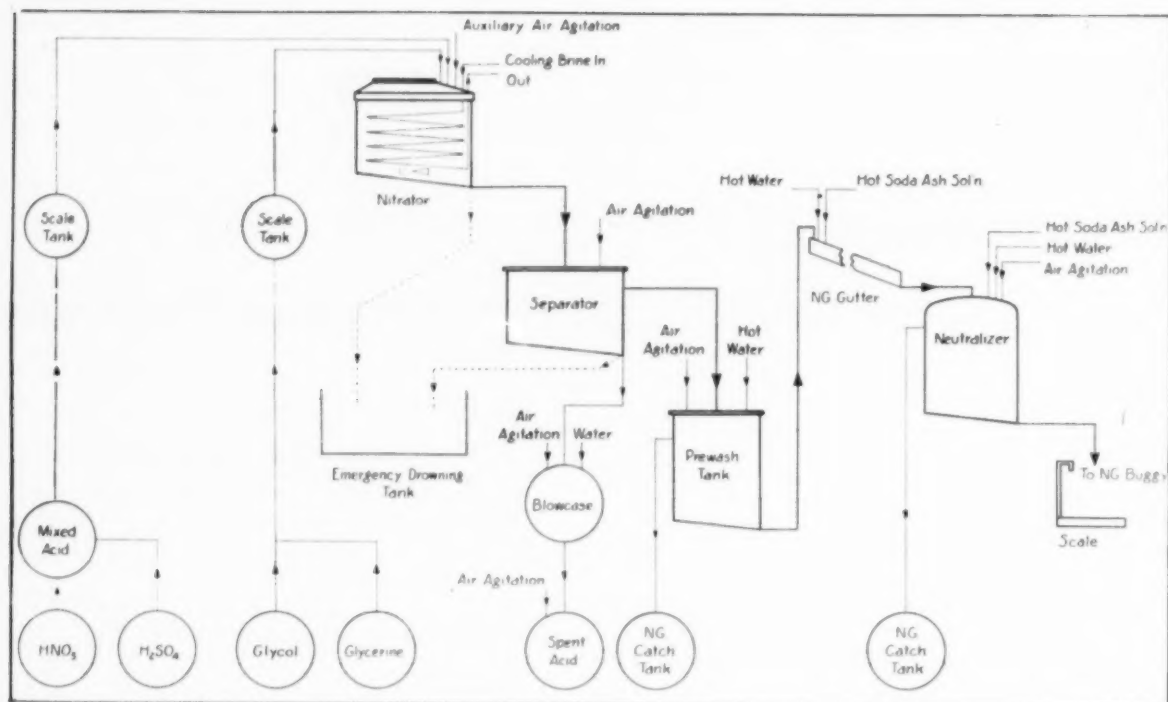
Fig. 1. Flow diagram of batch nitroglycerine process.

cessories the equipment in the nitration section is made of 18-8 stainless steel. The inner surfaces of the apparatus containing nitroglycerine are highly polished in order to avoid trapping nitroglycerine on rough surfaces. No valves are in the path of nitroglycerine, which is able to flow freely from the nitrator to the final storage tanks, and all totally enclosed spaces have a drainage hole at their lowest point to prevent accidental holdup of any nitroglycerine leakage. Thus no drop of nitroglycerine can remain stagnant in the apparatus either during operation or after the closing down of manufacture.

Glycerine, ethylene glycol, and mixed acid are stored outside in separate tanks. Provision is made for heating the glycerine and glycol in the storage tanks, but the mixed acid temperature fluctuates with outdoor conditions. Spent acid is stored in a separate building. A refrigeration unit of 50-ton capacity is installed in the basement of the nitration building.

A flow diagram for the Biazzi process is shown in Figure 1 and, for comparison, a flow sheet of the batch process is given in Figure 2. Figure 3 is a photograph of the nitration section of the Biazzi plant. The principal equipment is described as follows:

1. Nitrator

The nitrator is an unlagged, stainless steel vessel, of 28 in. diam. by 35 in. high. Five sets of spiral cooling coils are closely packed in parallel inside the vessel, the two inner banks being of smaller diameter than the three outer banks. All the coils are welded together by stainless steel straps to form a unit which is suspended from the cover of the nitrator.

The impeller-type stirrer is composed of curved radial vanes welded to a dished bottom plate, perforated to allow drainage of nitroglycerine. The shaft is solid and has only a small clearance from the hole in the nitrator cover through which it passes. The top of the shaft is enclosed in a housing, which also conceals the ball race and V-belt drive from an electric motor. The motor is situated in a compartment separated from the nitrator by a wall. A flywheel is attached to the motor, and has the effect of preventing a sudden jerk on starting, and of prolonging the stirring action for a short time after the power is shut off.

The cover of the nitrator is provided with a round glass inspection window, fume pipe, mixed-acid feed pipe, hole for stirrer shaft, hole for glycerine nozzle, and inlet for separating oil. The cover is separated from the top of the nitrator body by a narrow lead or asbestos washer, but it is not attached to the body. The body has a rounded bottom, without baffles, at the center of which is located an inlet for displacement acid. For emergency drowning of the nitrator contents there is a

6-in.-diam. bottom opening, closed with a stainless-steel flap valve held in place by a lever and toggle joint arrangement, which may be released either by hand or by means of compressed air. The drowning orifice is at one side of the nitrator bottom in order to be effective even when the stirrer is running. An emulsion overflow pipe is welded tangentially to the body of the nitrator a few inches below the cover.

The body is supported by means of a bracket at the back of the nitrator and this is free to move vertically on a slide, the weight being taken on a cable which passes over a pulley in the wall to the motor room where it is attached to a weight. This permits the nitrator casing to be lowered for inspection of the cooling coils, although before lowering the casing it is necessary to disconnect three flanges.

The glycerine and ethylene glycol are pumped from their respective storage tanks by individual precision volume pumps operated from a common variable-speed drive. The two flows are mixed and enter the nitration building as a single stream. The mixed acid is delivered to the nitrator by a Wilfley stainless-steel, centrifugal pump.

The acid enters the nitrator through an open pipe but the glycerine and glycol are passed through a pivoted pipe to a nozzle containing apertures to divide the feed into seven thin streams. Both the acid and the glycerine-glycol are introduced from the top of the nitrator along the shaft of the stirrer. They are drawn

Table 1.—Comparison of Biazzi and Batch Nitrators

(Output: 2,500 lb. nitroglycerine/hr.)

	Biazzi	Batch
Nitrator capacity—U. S. gal.	32	810
Total cooling surface—sq.ft.	122	258
Unit cooling surface—sq.ft./gal.	3.81	0.32
Time in nitrator—min.	4.2	50
Heat transfer—B.t.u./(sq.ft.)(hr.)(° F.)	150	69
Brine inlet temperature—° F.	28	−13 to −3
Nitroglycerine in nitrator (at 4·7:1 acid ratio)—lb.	170	3,500

toward the bottom by the impeller, mixed, and thrown outward by centrifugal force toward the walls. Reaction is extremely rapid and the emulsion of nitroglycerine and spent acid rises in a spiral movement around the cooling coils. Part of it leaves the nitrator by an overflow, while the remainder is drawn to the center and down once again.

The advantages of the Biazzi nitrator in comparison with the batch-type nitrator are:

1. More efficient agitation and greater speed of circulation, thus avoiding any local overheating and oxidation of glycerine.

2. Improved heat transfer between the reactants and the cooling medium, be-cause of the greater cooling surface per unit volume.

3. Better approach to countercurrent cooling owing to the regular flow of liquid along the cooling coils.

4. Smaller quantity of nitroglycerine in process. A numerical comparison of some of these factors is given in Table 1.

2. Acid Separator

The Biazzi separator is shaped like a centrifuge 5 ft. 3 in. diam. by 3 ft. 4 in. high. The interior is empty in contrast to the Schmid separator which contains a large number of baffle plates. The emulsion overflowing from the nitrator enters the separator tangentially. The rotation imparted to the emulsion aids the agglomeration of the droplets of nitroglycerine. Separated nitroglycerine overflows through an outlet pipe, while the spent acid is withdrawn from the bottom and through an overflow of variable height, which can be adjusted so as to have the separation level at the desired height. An emergency drowning system is provided similar to the one in the nitrator. Glass sights are placed for convenient observation of the process.

The chief advantage of the Biazzi separator lies in the decreased amount of separated nitroglycerine present at one time, amounting to about 110 lb. compared with 1,000 lb. in a Schmid separator and 3,500 lb. in a batch separator.

3. Washers

The nitroglycerine leaving the separator contains about 6% HNO_3 and 0.3% H_2SO_4 which must be removed in order to obtain a stable product. The washing is done in a group of three small, covered, stainless-steel vessels (19 in. diam. × 33 in. high) equipped with agitators similar to the one used in the nitrator. The acid-wet nitroglycerine is run into the first washer with an equal volume of 13% sodium carbonate solution. The heat of reaction is removed by a cooling water jacket so that the emulsion temperature does not exceed 95° F. Any gases

Fig. 2. Flow diagram of Biazzi nitroglycerine process.

Fig. 3. Nitration section of Biazzi plant at Calgary, Alta.

quite sensitive to changes in the composition of the spent acid.

In order to avoid an after-separation of nitroglycerine from the spent acid on standing, a small amount of water (2 to 4%) is added to the acid in a diluting vessel through which the spent acid flows upon leaving the separator. The spent acid may then be denitrated to recover weak nitric acid (60%) and sulfuric acid (70%). A quantity of spent acid is held in an overhead tank and used for displacement when the plant is shut down.

To shut down the plant, the feeds of glycerine and mixed acid are shut off and the nitrator stirrer stopped. Spent acid is then admitted through the bottom of the nitrator, displacing the nitroglycerine upward until it has all overflowed into the separator. The overflow on the separator is adjusted so that spent acid rises and pushes the last of the nitroglycerine out of the separator into the first wash tank. Upon stopping the agitator in the first wash tank, the pumping action of the agitator in the second wash tank is sufficient to pull the contents of the first wash tank through a bottom connection into the second. The same procedure moves the remaining nitroglycerine emulsion to the third washer, from which it flows by gravity to the water separator, leaving all three washers empty. When shutting down for the night the acid separator and the nitrator are left partially filled with spent acid ready for the next start-up. In the case of a more prolonged shutdown the separator is emptied through the dilutor. It requires about 15 min. to clear the plant of nitroglycerine after the glycerine feed has been shut off.

5. Safety System

One of the major concerns in any continuous nitroglycerine process is the system of controls or safety devices. The safety system on the Biazzi unit is designed with the following aims in view:

1. To prevent any operating errors which might cause a hazardous situation.

2. To attract the operator's attention to any irregular functioning of the unit.

3. To allow the operator to act to prevent damage or disaster arising from any irregular functioning of the unit.

4. To set in action automatic devices should the intervention of the operator fail to counteract the irregular functioning.

To accomplish these aims certain safety features are built into the electrical system and, in addition, a number of other controls are designed to respond to hazardous conditions. The latter are on a separate, battery-powered electric circuit and will operate only when the "securities" switch is turned on. In starting up the unit, switching on the mixed acid pump causes a red light to show if the securities switch is not turned on.

evolved are removed through a fume pipe which enters the washer from the back. The cover carries the soda inlet and an inspection opening with a removable polyethylene lid.

The second and third washers are similar to the first except that they have no cooling jacket or soda inlet. Their purpose is to ensure thorough neutralization of the acid in the nitroglycerine.

After overflowing from the third washer, the emulsion of nitroglycerine and soda water flows by gravity through a pipe line to another building, about 300 ft. away, which houses two separators, a catch tank for wash waters, and the nitroglycerine storage tanks. An interruption funnel is installed in the line carrying the emulsion in order to provide a break which prevents any communication between buildings as a result of a thin film of nitroglycerine being in the line. Water is introduced at the funnel in sufficient quantity to prevent deposition of salts in the soda water separator.

The wash water separators consist of two vessels, each of 200-gal. capacity and similar in principle to the separator in the nitration house. Nitroglycerine separated in the first vessel is jetted into the second by means of a manually controlled water eductor. From the second separator the nitroglycerine flows to storage tanks. Wash liquor is accumulated in a 2,500-gal. catch tank, from which it overflows to sewer.

4. Spent Acid

The spent acid leaving the acid separator usually contains less than ½ lb. of nitroglycerine/ton of acid in suspension. In addition there is a certain amount of nitroglycerine dissolved in the acid, the actual amount in solution being

Table 2.—Raw Materials and Labor Required by Biazzi and Batch Processes

(per 100 lb. dry nitroglycerine)

		Biazzi	Batch
Glycerine (50% ethylene glycol)	lb.	42.8	42.8
Sulfuric acid *	lb.	101	99
Nitric acid *	lb.	104	99
Sodium carbonate	lb.	8.0	1.7
Operating labor	man-hours	0.09	0.18
Maintenance labor	man-hours	0.04	0.08

* Gross input as 100% acid. No allowance for recovery from spent acid.

Whether or not the securities switch is on, the following controls operate:

1. The mixed acid pump will not operate unless the nitrator agitator is up to speed.

2. A system of green and red lamps indicates if the brine pump and soda water pump are on or off, and whether the temperature of the first soda washer is low or high.

3. The glycerine feed pump will not run unless the mixed acid flow is up to the required flowmeter setting. Low mixed acid flow is indicated by a red light and a horn.

4. A green lamp shows when the refrigeration compressor is running, and another shows when the spent acid pump is on.

5. Contents of the nitrator and separator can be drowned in water by means of a hand-operated air valve.

When the securities switch is on, the following additional controls operate:

6. The glycerine and mixed acid flows are stopped if the temperature of either the nitrator or separator rises to the first set point.

7. If the temperature of the nitrator or separator rises to the second set point, both charges are automatically drowned.

8. Low flow of soda water or slow speed of the first soda washer agitator is indicated by a light and a horn.

Plant Operation

The Biazzi plant requires only two operators. During the start-up and shutdown, the operators are occupied adjusting the various flows, but otherwise the unit requires only minor adjustments at infrequent intervals.

Because the unit is fabricated of stainless steel throughout, corrosion is negligible and maintenance costs are lower than for the batch process.

A summary of the requirements of raw materials and labor is given in Table 2, which also includes comparative figures for the batch process.

The consumption of raw materials by the Biazzi process is not appreciably different from the batch process except in the case of soda ash. The lower consumption of this material in the batch process is due to the use of water for a prewashing operation which follows the separation of the nitroglycerine from the spent acid and precedes the soda-washing step. In the Biazzi process the entire acidity of the seperated nitroglycerine is neutralized by soda ash, and an excess is employed as a precautionary measure and to prevent fuming in the first washer.

The utilities required for the Biazzi process are considerably less than for the average batch process. About 1 kw.-
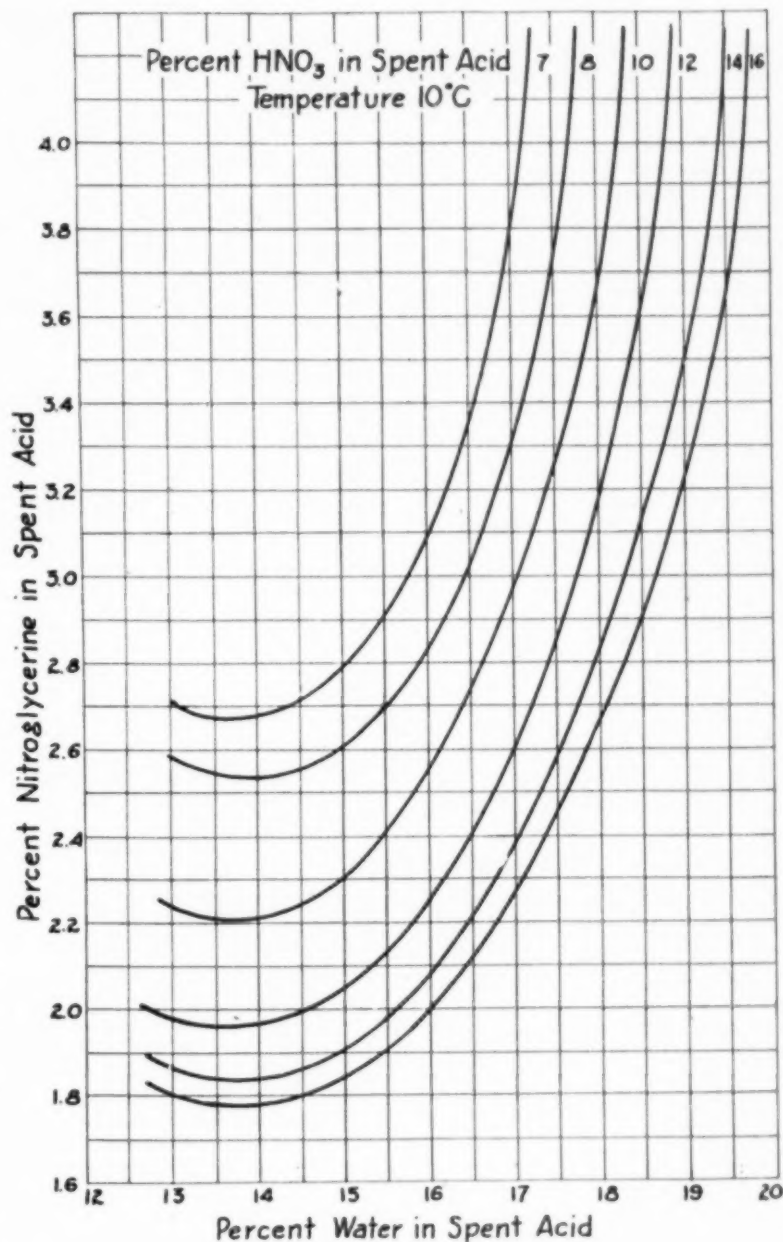
Fig. 4. Solubility of nitroglycerine in spent acid.

hr. of electricity is required/100 lb. of nitroglycerine for agitator drives. Water requirements are about half those for the batch process, and no steam is needed except for heating of the buildings.

Refrigeration requirements for the Biazzi process are about 25% lower owing to the improved heat transfer to the cooling coils in the nitrator. This permits the use of refrigerant at a higher temperature (see Table 1) and consequently decreases losses in the refrigeration system.

The use of a relatively high-temperature cooling brine in the nitrator coils has another advantage when pure glycerine is being nitrated. The freez-

ing point of nitroglycerine is 56° F., and, though the nitration is carried out at 58° to 62° F., there is always the danger that nitroglycerine may freeze in contact with the cooling coils. This danger is much less in the Biazzi process where the brine is at 28° F., than it is in the batch process where the brine enters at —13° F. Frozen nitroglycerine is much more sensitive to initiation by friction than is the liquid material. The danger of freezing is greatly lessened when a mixture of glycerine and glycol is nitrated. Nitroglycol freezes at—6° F., and a mixture of equal parts of nitroglycerine and nitroglycol freezes at about —75° F.

In practice the Calgary plant is nitrating at a temperature of about 54° F. The temperature of the glycerine and glycol feed is maintained if possible in the range 70° to 80° F., but the mixed acid temperature varies with the ambient temperature outdoors.

The acid used for nitration is made by mixing 40% oleum with strong nitric acid, and has a negative water content, i.e., contains free SO_3. A typical analysis is shown in Table A.

Table A.

	Wt. %		Wt. %
H_2SO_4	49.0	$HNOSO_4$	0.6
HNO_2	52.0	H_2O	—1.6

There is a correlation between the yield of nitroglycerine and the total acidity of the mixed acid. In general the yield increases with an increase in the total acidity, but the gain per unit increase in acidity falls off rapidly above 100% total acidity. Economically it is necessary to balance the savings from a higher yield against the increased cost of producing the stronger nitric acid needed to make the mixed acid of higher total acidity.

The yield of nitroglycerine is also dependent upon the nitric ratio, i.e., the pounds of nitric acid/100 lb. of glycerine. For a given total acidity of the mixed acid, the yield increases with the nitric ratio, passing through a rather flat maximum. The most economical nitric ratio depends in part upon the net cost of using the excess nitric acid, which does not combine to form nitroglycerine. The nitroglycerine operation is charged, in effect, for the cost of concentrating the nitric acid in the spent acid. It is necessary to balance the yield savings against the net price of excess nitric acid. The nitric ratio used at the Calgary plant is about 248 lb. HNO_3/100 lb. glycerine.

One other variable of importance in the nitration reaction is the D.V.S.

(dehydrating value of sulfuric acid) of the mixed acid. The D.V.S. is an empirical concept defined as the ratio of the actual content of sulfuric acid in the mixed acid to the water content of the spent acid. Both the yield of nitroglycerine and the rate of reaction are dependent upon the D.V.S. The D.V.S. used at Calgary is about 4.45.

Routine control of the operation is based upon the composition of the spent acid. The curves in Figure 4 show how sensitive is the solubility of nitroglycerine to changes in the composition of the spent acid. To obtain the best yield, therefore, it is necessary to control the composition of the spent acid within narrow limits. The water content of the spent acid should be about 14 to 15%, slightly higher values being allowable when nitrating mixtures with a high content of ethylene glycol. The nitric acid content of the spent acid is normally kept around 10%. Higher values would reduce the nitroglycerine loss in the spent acid, but would involve the use of a higher nitric ratio which, as already mentioned, is not economical because of the cost of concentrating the excess nitric acid.

General Remarks

The most important advantages of the Biazzi process over other systems of nitroglycerine manufacture are the following:

1. Not only is the quantity of nitroglycerine in process much smaller than for the batch system, but most of this quantity is emulsified with either acid or wash liquor. It has been demonstrated that these emulsions are insensitive to a No. 6 blasting cap.

2. Owing to the compact nature of the Biazzi equipment, the building requirements are considerably less than for the batch system. All the nitration equipment is housed in a room 30 ft. x 14 ft.. x 12½ ft. high, and the total floor area of the nitrator building is 740 sq.ft. As a consequence the cost of buildings, mounds, or barricades is less than for the batch system.

3. All equipment is on one floor and no heavy apparatus is placed upon or below the roof. Thus in case of an explosion there will be no heavy missiles.

4. The automatic safety devices greatly decrease the dependence on human vigilance for the safety of the operation. The safety record of Biazzi plants is outstanding. No fatal accident has ever occurred.

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Discussion

O. J. Wolff (Allied Chemical & Dye Corp., New York): Have you any information about the flexibility and capacity of these units? Through what range vs. graded capacity can you operate them?

J. M. Humphrys: You mean at what percentage of capacity did our plant actually operate?

O. J. Wolff: No. With respect to the rating and the unit I think you had a 2,500 lb./hr. Does it maintain its rated capacity and at what per cent of that capacity can it safely be operated?

J. M. Humphrys: The plant operates practically at its designed capacity or slightly below. That is simply because conditions at the plant have not yet required an all-out operation. We believe,however, that we can operate this plant at least 5% above its rated capacity.

O. J. Wolff: In the event of slowdowns is it possible to cut it to half-rate with instrumental control provided?

J. M. Humphrys: Yes, but we believe it is more satisfactory actually to operate the plant at or near its designed rate, and then shut it down if the output is not needed.

Presented at A.I.Ch.E. Toronto meeting.

CORRECTION

The paper "Measurement and Correlation of Thermal Conductivities of Gases at High Pressures" by J. M. Lenoir, W. A. Junk, and E. W. Comings (see "C.E.P.," October issue, page 539) is based on the Ph.D. theses in chemical engineering by W. A. Junk and J. M. Lenoir carried out at the University of Illinois. The equipment and support for the research were supplied from University of Illinois funds. The paper was erroneously attributed to Purdue University, Lafayette, Ind. E. W. Comings, one of the authors, is associated with Purdue University, and as stated in "C.E.P.," J. M. Lenoir and W. A. Junk are with the University of Denver and Standard Oil Company, respectively.

TELOMERIC REACTIONS OF ETHYLENE AND ALCOHOLS

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A continuous high pressure system was constructed for studying solvent polymerization of ethylene. The ethylene was continuously recycled at 400 g./hr. through a 360-cc. reactor. The solvents, methyl, ethyl, isopropyl, and tertiary butyl alcohol, containing di-tertiary butyl peroxide as the initiator, were fed at rates up to 1000 g./hr. The study covered the range 1,000 to 8,000 lb./sq.in. and 120 to 190° C. The analysis of the products, ranging from oils to waxes, indicated that the primary and secondary alcohols telomerize to form long-chain alcohols whereas the tertiary alcohol was inert. The polymerization rates increased with temperature, pressure, ethlene purity, and peroxide concentration.

Patent literature (4) defines telomerization as the process of reacting under polymerization conditions, one molecule of a telogen (any saturated organic compound containing only carbon, hydrogen and oxygen) with more than one molecule of a polymerizable compound such as ethylene. The patents state further that all saturated alcohols are telogens but give no definite analytical proof that the alcohols actually enter into the polymerization reaction. In fact there has been contrary evidence. Hopf and Goebel (2) describe the synthesis of Lupolen N wax in Germany as a high pressure polymerization of ethylene in the presence of methanol, initiated by benzoyl peroxide. Although they noted that the wax contained more combined oxygen than could be attributed to oxygen released from the peroxide, they concluded that it was the resulting benzoic acid and not the methanol that was entering into the reaction.

It was noted, in the course of studying ethylene polymerization in a high pressure rocker tube, that higher yields of wax products were obtained when certain alcohols were used as solvents. A continuous high pressure polymerization system was therefore set up to study the rates of ethylene polymerization in various solvents. Analysis of the low-molecular-weight waxes obtained from the early operation of the unit indicated

that they contained significant quantities of hydroxyl groups. The rest of the investigation was devoted to determining the nature of the reactions. Therefore, most of the operation of the continuous polymer unit was restricted to the low pressure of 1,000 lb./sq.in. in order to obtain polymer low enough in molecular weight to permit ready analysis.

Description of Equipment

The continuous polymerization unit was designed for operation up to 25,000 lb./sq. in., but, except for pressure-testing it at this range, its maximum operation in this study was at 8,000 lb./sq.in. Figure 1 shows the flow diagram of the system. Ethylene of 99.5% purity was passed at 15 lb./sq. in. over hot reduced copper to remove the oxygen and then metered into the suction side of a two-stage air compressor converted for use with ethylene. This compressor had a capacity of about 400 g./hr. at 1,000 lb./sq. in. discharge pressure and atmospheric suction. A single-stage water-cooled plunger-type pump was then used to boost the pressure to the desired level. For pressures of 1,000 lb./sq. in. and below this pump was by-passed. After passing through a small silica gel and activated charcoal trap, the ethylene from the compressor or pump entered the bottom of the reactor through a small orifice, thereby providing a jet type of agitation and mixing. The alcohol solvent containing the requisite quantity of ditertiary-butyl-peroxide initiator was metered to the reactor by a single-stage high pressure variable-stroke pump. Again a jet entry was used to provide additional agitation. The product mixture left the reactor through an overflow tube and was let down to atmospheric pressure by means of two regulator valves in series. The product and the solvent alcohol were removed from the gas by two Erlenmeyer flask separators operated alternately. The gas was passed through a cold trap to remove solvent in order to prevent interstage condensation and was then recycled back to the suction of the two-stage compressor.

A cross section of the 360-cc. reactor is shown in Figure 2. The reactor body was machined from type 4145 steel and was 1.73 in. I.D. by 4 in. O.D. with 15-in. over-all length. It was heat-treated to a hardness of about 33 Rockwell C with an expected yield point of 120,000 lb./sq. in. minimum. With these characteristics the vessel reached yield point at about 60,000 lb./sq. in. The reactor body was plated with 2-3 mils of pure nickel. The body of the reactor was closed by means of two floating heads which, together with backing nuts and gasket rings, formed a self-sealing closure similar to that described by Clark et al. (1). The heads were made from type 416 stainless steel and were heat-treated to obtain maximum hardness. The backing nuts, made of type 4140 steel, carried a four-pitch buttress thread and were hardened to a Rockwell C 50. The gasket rings were machined from a cold-rolled Monel bar and were used without heat treatment. One of the heads carried a nickel rupture disk and the other was drilled and tapped for a thermocouple well and three process streams. Two of these were fitted with 0.010-in.-diam. orifices and the third with an overflow exit tube. Process stream connections were made by means of a collar and standard cone-type fittings for 1/4 in. by 1/16 in. tubing. The entire reactor was heated by a nearly full length steam jacket sealed with O-rings. This O-ring closure was not entirely satisfactory because 175-lb./sq. in. steam tended to harden the rings after a short time so that, when cold, they would not reseal for the first few minutes after steam was turned on. However, 100 hr. of intermittent operation was possible before the rings no longer sealed after a short warm-up period, thus, the disadvantage was far outweighed by the simplicity of the O-ring closure.

Primary compression up to 1,000 lb./sq. in. was done by a two-stage war surplus aircraft air compressor (General Electric). To modify the compressor for use with ethylene, the original 27-v. motor and gear reducer were removed and replaced by a housing containing a stub shaft, bearings, and a mechanical seal. The compressor was then driven at 600 rev./min., about 1/3 of its design speed, by a ½ hp. motor. The air-intake filter was removed and an intake manifold fitted into its place.
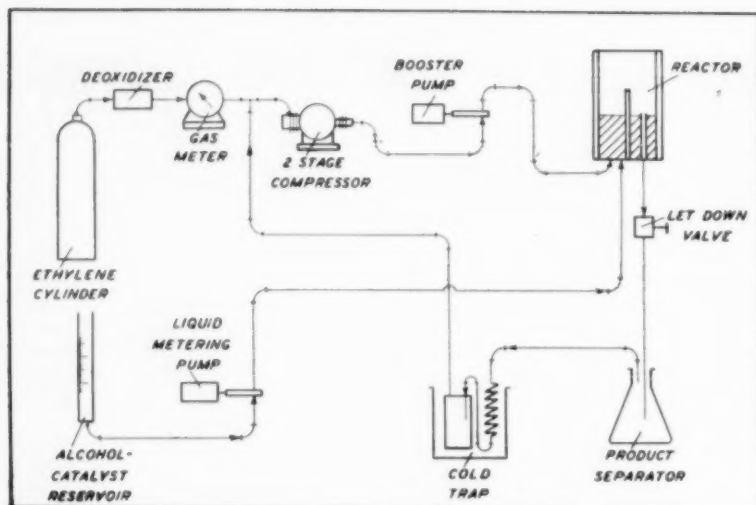
Fig. 1. Flow diagram of continuous polymerization unit.
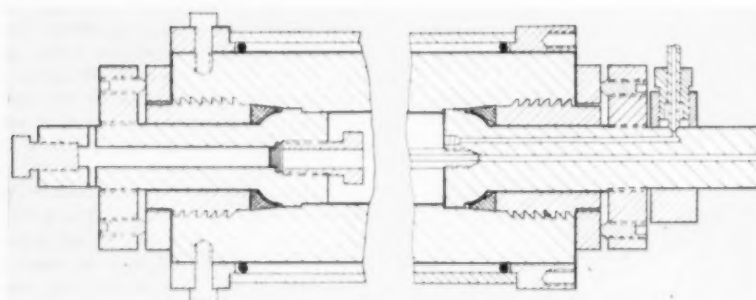
Fig. 2. Reactor assembly.
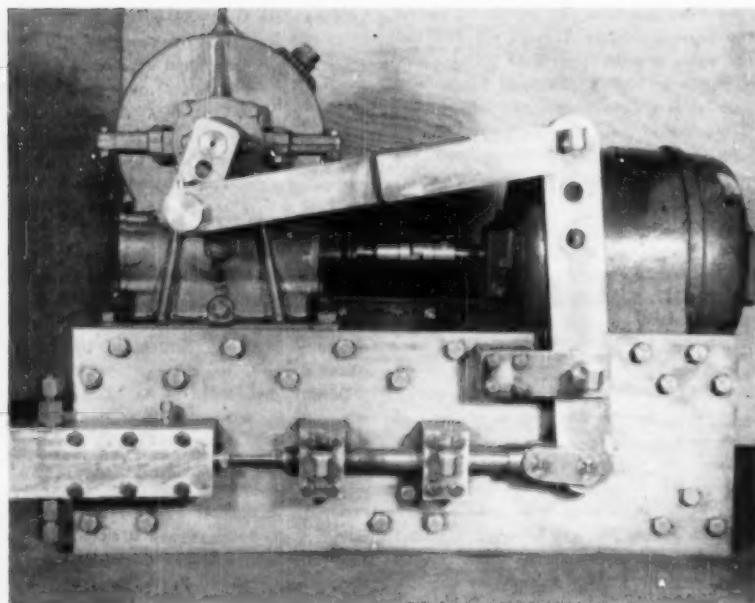
Fig. 3. Pump, 2,000 atm.

The crankcase was vented to the first-stage suction to collect leakage past the pistons. Feed rate to the reactor was established by a capacity calibration of the compressor at 800 and 1,000 lb./sq. in. as a function of suction pressure and temperature.

Figure 3 shows the booster pump for compressing ethylene above 1,000 lb./sq. in. A single stage was adequate for this purpose, inasmuch as the ethylene at 1,000 lb./sq.in. and room temperature is near its critical condition and relatively incompressible. The pump had a 5/16 in. diam. piston with a 2⅜ in. stroke. Valves were conventional spring-loaded balls, two in series each in the intake and exhaust sides of the pump. The valve seats were made in lens rings to facilitate grinding, lapping, and assembly. A careful arrangement of two lantern rings and three sections of chevron-type leather packing rings sealed the piston. The first lantern ring collected any gas leakage past the first section of packing and returned it to the inlet side of the pump. The second lantern ring received oil at suction pressure plus about a 4-ft. head. This was followed by a final series of packing rings to seal the oil. This pump was driven by a 1½ hp. 1,750 rev./min. motor through a 24½/1 gear reducer.

The high pressure liquid metering pump was similar to the booster pump except that it had a 3/16 in. diam. piston and was driven with a ½ hp. motor. The stroke length could be varied by changing either the stroke of the crank or the pivot point of the lever arm.

Other miscellaneous equipment constructed for this system was a high pressure reducing regulator valve for serving as a letdown valve and high pressure block valves. These block valves accepted standard cone-type fittings for ¼ in. high pressure tubing.

Results

The first series of runs was made with isopropyl, ethyl, methyl or tertiary butyl alcohol with the object of making low molecular-weight polymers. Typical operating conditions are shown in Table 1. These results are the averages of 2-to-4 hour operation after a one-half to one-hour leveling period.

The products after removal of the residual alcohol were mixtures of oils and greases with low melting points.

Ethylene and Isopropyl Alcohol

Infrared analysis of this product indicated that it contained considerable quantities of tertiary hydroxyl groups but little unsaturation. After simple distillation, the recombined product showed less hydroxyl and more unsaturation. This condition appeared almost entirely in the high (>250°C.) boiling fraction, suggesting that dehydration had occurred during distillation. By means of fractional distillation through a packed column of some forty theoretical plates, it was possible to separate

C₂H₄ feed rate (recycle and make-up)	410 g./hr.	
Alcohol feed rate	600 cc./hr.	
Di-t-butyl-peroxide	40 g./l. in the alcohol	
Pressure	975 lb./sq.in.	
Temperature	185-190° C.	

	PRODUCT RATE	MAKE-UP ETHYLENE RATE
Isopropanol	119 g./hr.	110 g./hr.
Ethanol	102	85
Methanol	33	...
t-butanol	71	70

the lower boiling portion of the mixture into constant-boiling fractions of relatively pure products which were then identified.

Figure 4 shows that these sharp fractions occurred every 40°C. starting at 100°C. These fractions have been identified as a series of dimethyl carbinols, which differ from the next in the series by one molecule of ethylene. Identification was made through the physical properties of boiling point, density, index of refraction and molecular weight, as well as chemical tests for tertiary hydroxyl. Shown in Figure 4 are the accepted values for boiling point of this series of alcohols. The value for 2-methyl 2-decanol was obtained by extrapolation from the boiling point at reduced pressure. No physical properties were found for 2-methyl 2-dodecanol.

It is concluded from these results that isopropyl alcohol was entering into the reaction according to the following equation

$$CH_3CHOHCH_3 + n\,C_2H_4 \downarrow$$

$$CH_3{-}\underset{\underset{(C_2H_4)_nH}{|}}{\overset{\overset{OH}{|}}{C}}{-}CH_3$$
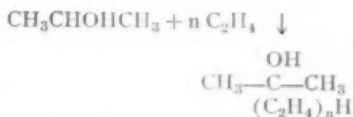
which is that described as telomerization.

The fractions below the boiling point of isopropanol contained considerable quantities of acetone, identified through the 2,4-dinitro phenylhydrazone derivative, and traces of an unsaturated hydrocarbon and an unkown aldehyde. It was also noted that the methane and ethane content of the recycling ethylene stream built up more rapidly than could be ac-

counted for by the content of these compounds in the make-up ethylene. These materials undoubtedly resulted from the breakdown of the di-t-butyl-peroxide initiator and will be discussed later.

Ethylene and Ethanol

From the preceding equation it is evident that the reaction between isopropanol and ethylene involves the hydrogen on the hydroxyl-containing carbon. On this basis it was possible to predict that primary alcohols would result in longer-chain secondary alcohols which in turn could react to give still longer-chain tertiary alcohols. Thus ethanol would give rise to a series of both secondary and tertiary methyl carbinols. The fractionation curve for the ethanol-ethylene product indicates that this is true (Fig. 5). The one-to-one addition product, 2-butanol, was found in considerable quantities. Higher homologs were 2-hexanol, 2-octanol, and 2-decanol. The first possibility in the tertiary series would be 3-methyl 3-pentanol arising from the reaction of 2-butanol and ethylene. No constant boiling fraction appeared at the appropriate boiling point but fractions in this region did contain tertiary hydroxyl groups and had the appropriate molecular weight. The next homolog, 3-

Fig. 4. Fractionation of ethylene-isopropanol telomerization product. Run C-20.

methyl 3-heptanol, which could arise from either 2-hexanol and one ethylene, or 2-butanol and two ethylene molecules, was present. Likewise present was 3-methyl 3-nonanol, which could again have arisen from two sources.

Ethylene and Methanol

Methanol is the only alcohol that could first give rise to primary alcohols with an odd number of carbon atoms. These of course could still telomerize to give a variety of secondary and tertiary long - branched - chain alcohols. One would expect the fractionation of this material to be exceptionally difficult and this proved to be quite true. It was possible to obtain constant boiling fractions only for the 3, 5, 7 and 9-carbon primary alcohols and even these fractions were of mediocre purity. However, positive identification of normal pentanol was made through the α-naphthyl phenyl urethan derivative and the others were identified by their physical properties plus a test for primary hydroxyl group.

Ethylene and Tertiary Butyl Alcohol

No telomerization between ethylene and the synthesized tertiary alcohols was observed. This was contrary to patent literature which stated that all saturated alcohols were telogens. To substantiate further this observation ethylene was polymerized in the presence of tertiary butyl alcohol. The unfractionated product was an oil that differed markedly from the other products. It did not solidify at ice temperatures and yet its viscosity at 100°C. was several times that of the isopropanol product. The oil had a high boiling point compared to previous products, with only some 10% boiling below 250°C. Fractionation through the 40-plate column gave no significant compound separation. This product did not release hydrogen from sodium as is characteristic of even high molecular-weight alcohols. By combustion analysis it contained no oxygen within experimental error. It was concluded therefore that telomerization with alcohols requires a hydrogen on the hydroxyl-containing carbon.

Mechanism

From the results described here it is concluded that the telomerization involves free radical transfer with the alcohol. The transferred free radical is sufficiently active to continue polymerization as evidenced by mole yields of at least nine times the moles of di-t-butyl peroxide catalyst.

Di-t-butyl peroxide is known to break down thermally to give two butoxy radicals:

$$CH_3C(CH_3)(CH_3)-O-O-C(CH_3)(CH_3)CH_3 \longrightarrow 2\ CH_3C(CH_3)(CH_3)-O- \tag{1}$$
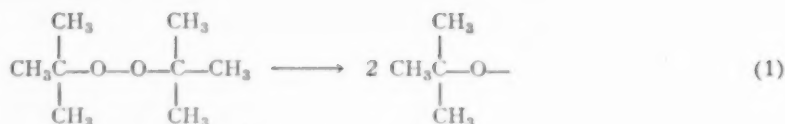
With hydrogen donors, these lead to t-butanol:

$$RH + CH_3C(CH_3)(CH_3)-O- \longrightarrow R- + CH_3C(CH_3)(CH_3)-OH \tag{2}$$
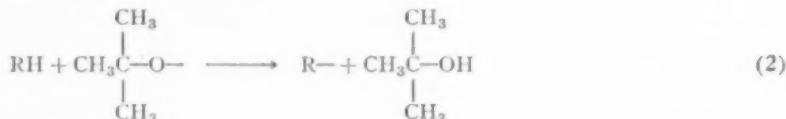
Otherwise the t-butoxy radical breaks down into acetone:

$$CH_3C(CH_3)(CH_3)-O- \longrightarrow CH_3-\overset{O}{\overset{\|}{C}}-CH_3 + CH_3- \tag{3}$$
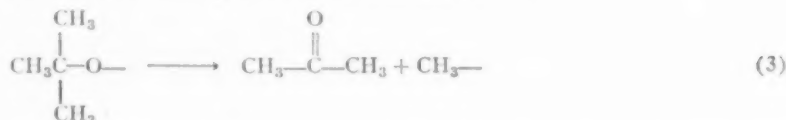
Both steps (2) and (3) occurred as indicated by the recovery of acetone and t-butanol.

The free radicals probably start the telomerization by reacting with the alcohol:

$$CH_3-\underset{CH_3}{\overset{OH}{C}}-H + CH_3- \longrightarrow CH_4 + CH_3-\underset{CH_3}{\overset{OH}{C}}- \tag{4}$$
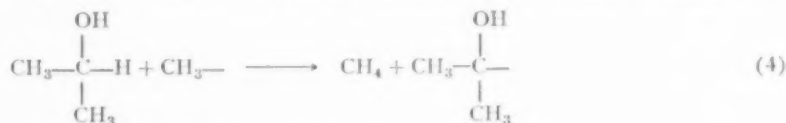
and the resulting hydroxy radical reacts with the ethylene:

$$CH_3-\underset{CH_3}{\overset{OH}{C}}- + nC_2H_4 \longrightarrow CH_3-\underset{CH_3}{\overset{OH}{C}}-(C_2H_4)_n- \tag{5}$$
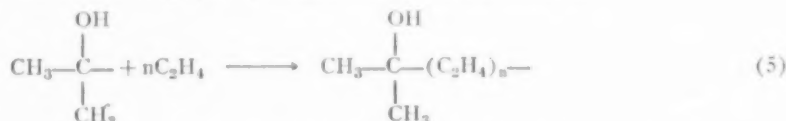
Chain transfer with the alcohol terminates a chain, but leaves a hydroxy radical free to start a new chain:

$$CH_3\underset{CH_3}{\overset{OH}{C}}-(C_2H_4)_n- + CH_3\underset{CH_3}{\overset{OH}{C}}-H \longrightarrow CH_3\underset{CH_3}{\overset{OH}{C}}-(C_2H_4)_nH + CH_3\underset{CH_3}{\overset{OH}{C}}- \tag{6}$$
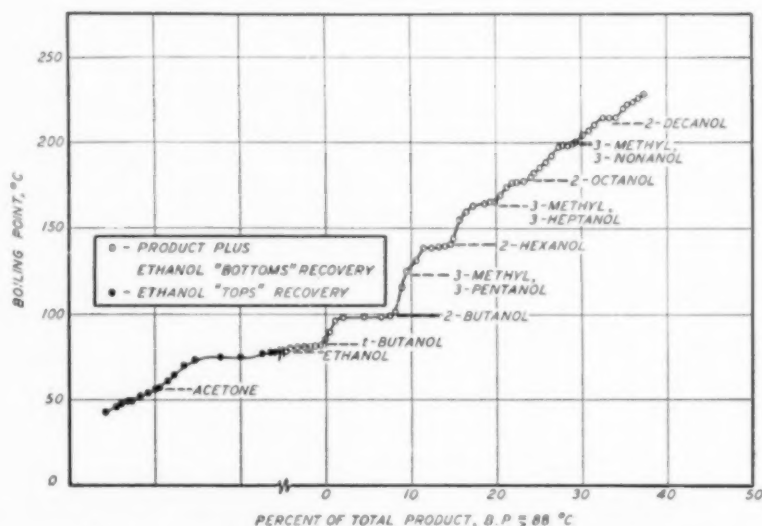
Fig. 5. Fractionation of ethylene-ethanol telomerization product. Run C-21.

Undoubtedly the t-butoxy and free methyl radicals are capable of attaching themselves directly to the ethylene, thereby giving a molecule without a hydroxyl group, but the low concentration of ethylene compared to the alcohol and the high free radical transfer rate do not favor such a reaction.

The methane noted in the recycle gas is explained by Equation (4). The ethane resulted by the recombination of two free methyl radicals.

Effect of Reaction Variables on Reaction Rate

The second portion of this investigation was directed toward determining the quantitative effects of some of the synthesis conditions on the rate of reaction. Table 2 presents the pertinent operating data for the effects of catalyst concentration, temperature, and pressure.

There were two reaction rates to consider. One was the rate at which ethylene was polymerized and this was measured by the rate that ethylene had to be fed to the system to hold pressure constant, corrected for known losses during sample changing. The second rate was that at which the product was recovered. Because each molecule of polymer contained one isopropanol molecule, the product rate was always higher than the ethylene rate. The ratio of these two rates was a measure of the number average molecular weight of the product. For the basic operating conditions just listed, the ethylene rate averaged 98 g./hr. and the product rate 119 g./hr.

Catalyst Concentration

In many peroxide-initiated polymerizations the rate is proportional to the square root of the catalyst concentration. This appears to apply to telomerization. In Figure 6 the slope of the line is 0.58, but in this series of runs it was difficult to keep the temperature constant on account of the exothermic reaction, so that temperature increased some 5° C. over the catalyst range of 2.5 to 40 g./l. The parallel lines of product and ethylene rate indicate that product to ethylene ratio, hence molecular weight, was essentially constant throughout the catalyst concentration range (ratio =

1.16 = molecular weight of 440). This implies that molecular weight was controlled by chain transfer with the isopropanol rather than by catalyst concentration.

Temperature

The study of temperature was limited to 190° C. and below by available steam pressure. In the lower part of the range the decomposition rate of di-t-butyl peroxide controlled the rate of reaction and masked the effect of temperature itself on polymerization rate. At 127° C., the half-life of di-t-butyl peroxide was about 9 hr.; at 190° C., about 45 sec.
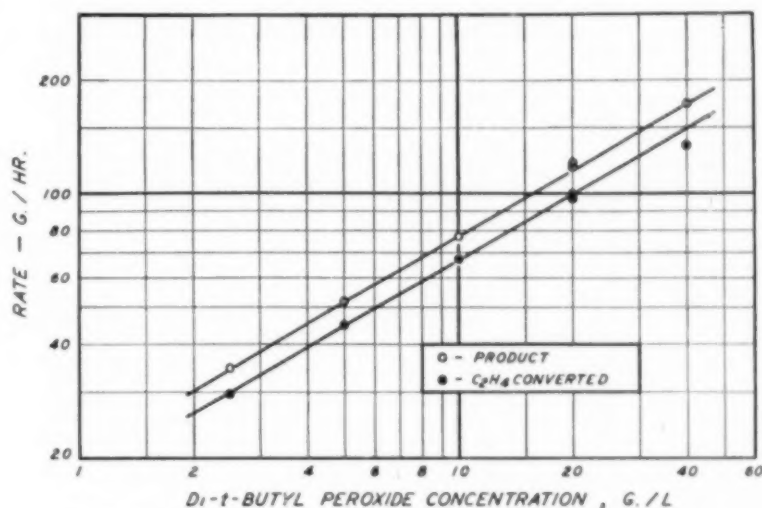
Fig. 6. Effect of catalyst concentration on reaction rate of ethylene and isopropanol.

Table 2.—Effect of Synthesis Variables on Reaction Rate [1]

RUN NO.	PRESS. lb./sq.in.abs.	TEMP. ° C.	DTBP g./l.	ISOPROPYL[2] ALCOHOL cc./hr.	ISOPROPYL[2] ALCOHOL g./hr.	MAKE-UP[3] ETHYLENE g./hr.	C_2H_4 CIR- CULATION g./hr.	AVG. C_2H_4 PURITY %	ISOPROPANOL RECOVERY g./hr.	PRODUCT RECOVERY g./hr.
BASIC RUNS										
C-23	975	190	20	614	477	100.5	411	94.2	448	117.1
C-28	975	190	20	612	475	103.8	409	96.7	440	120.4
EFFECT OF CATALYST CONCENTRATION										
C-27	975	185	2.5	610	474	37.7[4]	418	....	464	34.6
C-26	975	186	5.0	617	479	53.0	418	....	451	51.6
C-24	975	188	10	607	473	71.2	411	....	445	77.0
C-25	975	190	40	606	472	138	407	94.1	419	172.0
EFFECT OF TEMPERATURE										
C-36	975	127	20	612	476	17.9	403	98.8	466	18.8
C-35	975	148	20	612	476	52.8	398	98.4	443	60.5
C-37	975	161	20	615	478	89.0	404	98.1	448	109.3
C-38	975	176	20	613	476	97.1	404	96.6	452	110.8
C-44	975	176	20	618	480	103.0	381	96.6	431	120.4
EFFECT OF PRESSURE AND PURITY										
C-30	975	189	20	600	465	71.4	413	71.5[5]	444	92.3
C-29	975	190	20	600	465	84.2	413	81.3[5]	443	103.2
C-45	1915	195	20	610	474	203.1	428	....	445	231.0
C-46	3850	195	20	616	479	287.1	436	97.9	416	331.7
C-47	7800	195	20	616	479	248.9	445	98.6	376	331.7

[1] All runs made with a 215-cc. liquid holdup in a 360-cc. reactor.
[2] Includes the di-t-butyl peroxide initiator.
[3] Not corrected for calculated 4-g./hr. loss during sampling.
[4] A 4-g./hr. leak discovered after Run C-27—probably present during C-26 also.
[5] C_2H_4 reduced by addition of prepurified nitrogen.

compared to the reactor holdup time of about 20 min. At the low temperatures little of the initiator decomposed in passing through the reactor and therefore the rate of polymerization should vary as the square root of the decomposition rate varies with temperature. At the high temperatures the initiator is completely decomposed and the polymerization rate should level off to show the true effect of temperature on reaction rate. Figure 7 shows that the experimental data indeed go through this transition. The slope of the line is close to one-half that of the decomposition rate of di-t-butyl peroxide. The last two points at the high temperature, since they show no change in rate, suggest that temperature does not affect polymerization rate. This would be rather unusual and it is more likely that increasing temperature lowers the solubility and hence concentration of ethylene in the alcohol and therefore compensates for the usual increase in reaction rate.

Pressure

The effect of pressure on reaction rate was studied over the range 975 to 8,000 lb./sq.in.abs. Results in Figure 8 have been plotted as a function of fugacity corrected for the average mole fraction of ethylene recycling through the reactor. Over most of the range the reaction rate is proportional to the logarithm of the fugacity. This applied even to runs in which the ethylene concentration had been reduced by the addition of prepurified nitrogen. The points at the highest pressure fall markedly below the others. There is no explanation for this other than noting that during the leveling-off period the reaction rate was much higher than indicated and it became necessary to stop catalyst and solvent feed for a short time to control temperature. Upon resuming catalyst and solvent feed, the reaction rate leveled off to the value shown.

Summary

It has been shown that:

1. Telomerization reaction is essentially a polymerization of ethylene in the presence of an active chain transfer agent.
2. In the case of alcohols having a hydrogen on the hydroxyl carbon, it involves the addition of one or more molecules of ethylene to the hydroxyl carbon, thereby producing alcohols of higher degree and higher molecular weight.
3. The reaction rate was proportional to the square root of the catalyst concentration and the logarithm of ethylene fugacity. In the range studied the effect of temperature appeared to be compensated by the decreased solubility of ethylene in alcohol at higher temperature.

Fig. 7. Effect of temperature on reaction rate of ethylene and isopropanol.

Fig. 8. Effect of pressure on reaction rate of ethylene and isopropanol.

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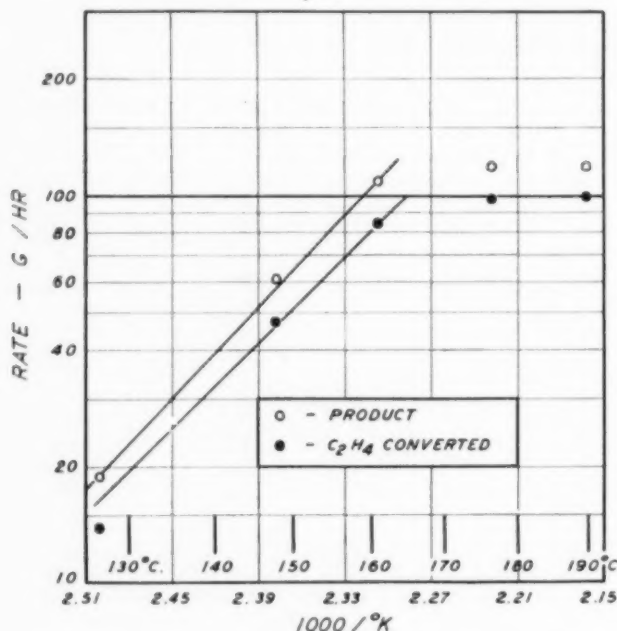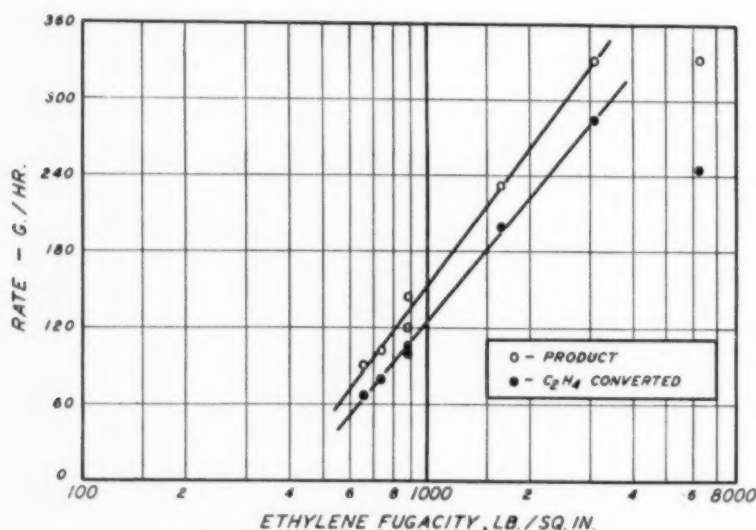# Natural-Convection Heat Transfer at Reduced Pressure

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Spheres and Cylinders

The need for basic engineering knowledge of rate processes at reduced pressures has been accentuated during the last decade by important developments in the design and availability of vacuum-producing equipment and by the increased use of vacuum processes in the food, pharmaceutical, metallurgical, and other industries.

In the present research, which is an extension of work by Madden and Piret (15), heat-transfer rates in natural convection from spheres and wires to several gases at reduced pressures are measured, and new generalized heat-transfer equations covering an extremely wide range of conditions are presented. Wires and spheres are advantageous forms to study because of the wide applicability of correlations based on these simple shapes. Heat losses at pressures ranging from 0.1 mm. Hg to atmospheric are determined for a 0.00306-in.-diam. wire in air, and for 0.312- and 1.000-in.-diam. spheres in helium, air, and argon. Solid temperatures up to 195° C. are employed, and subtractions are made for radiation to obtain the net heat loss. For the vertical-wire data, radiation does not exceed 5% of the total heat loss, but for the sphere data, values up to 35% are encountered.

It is customary to correlate natural convection data by relating the Nusselt number to the Grashof and Prandtl numbers and ignore the effect of free-

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At low gas pressures the thickness of the convective boundary layer is large and the effect of free-molecule conduction, important. These effects can be accounted for to give a single natural-convection heat-transfer correlation for both spheres and horizontal cylinders. This involves two departures from classical practice: (1) The characteristic length used in the dimensionless Grashof number becomes the diameter of the solid plus twice the mean free path length of the gas, and (2) the concept of a conductive film having the same resistance to heat transfer as that of the convective boundary layer is used instead of the Nusselt number to effect the single correlation.

Heat-transfer data are presented to demonstrate that for spheres and horizontal cylinders, the correlating term is the same function of the product of the Grashof and Prandtl numbers. This unique relationship holds over a wide range of Gr·Pr values from 10^{-7} to 10^{+10}. Useful equations, based on this correlation, are presented for calculating heat-transfer rates.

New data at pressures ranging from 0.1 mm. Hg to atmospheric are presented for spheres in air, helium, and argon, and for a vertical wire in air.

molecule conduction (4, 13). This effect, which, as will be seen, can be very significant, is accounted for in the general heat-transfer equations which will now be developed.

Development of General Heat-Transfer Equations

Figure 1 represents a heated sphere or horizontal cylinder of diameter D at a uniform temperature t_w, losing heat exclusive of radiation at the rate q, to a gas which has a uniform temperature of t_g at a distance of $\frac{1}{2} b'$ from the center of the solid.

If the argument of Blodgett and Langmuir (3) is pursued, it is assumed that heat is lost by free-molecule conduction from the solid through the gas for a distance equal to λ_a, which is the mean-free path of the gas at a temperature of t_a. The temperature distribution for this process is represented by the solid line from t_w to t_a in Figure 1, and the rate of heat loss (4) is

$$q = S a \lambda_a P \sqrt{\frac{273.2}{T_a}} (t_w - t_a) \qquad (1)$$

where S is the surface area of the heated solid, λ_a is the free-molecule conductivity of the gas at 0° C., P is the gas pressure, and t_a is the gas temperature at a distance of λ_a from the solid surface. The accommodation coefficient (13) a is a measure of the extent to which impinging gas molecules attain thermal equilibrium with the solid.

Beyond a distance of λ_a from the solid, heat is lost by convection, also at the rate q, into a boundary layer (5) of width B. The temperature beyond the outer edge of this layer is essentially the ambient temperature t_g. The upward flow of gas within this boundary layer has been shown to be laminar at values of the Grashof number lower than about 3.5×10^8 for horizontal cylinders and vertical walls (5, 9). The solid line from t_a to t_g represents the temperature distribution within the boundary layer, and

Vol. 49, No. 12   Chemical Engineering Progress   Page 653

the following correlation is proposed for heat loss to this layer:

$$(Nu)_{d',m} = f(Gr \cdot Pr)_{d',m} \qquad (2)$$

where f is a different function for spheres than for horizontal cylinders, and the subscripts d',m indicate that the dimensionless groups are evaluated using D' (Figure 1) as the diameter, $t_a - t_g$ as the temperature difference, and $(t_a + t_g)/2$ as the temperature at which the physical properties of the gas are determined.

Use is now made of the concept of an equivalent stagnant-gas film of diameter b, through which the rate of heat loss is also q and through which heat flows by ordinary conduction. The temperature distribution through this equivalent concentric-film is represented by the dotted line from t_a to t_g, and the rate of heat loss is expressed by the ordinary conduction equations

$$q = 2\pi k_{a,g} \frac{t_a - t_g}{\dfrac{1}{D'} - \dfrac{1}{b}} \text{ for spheres} \qquad (3)$$

and

$$q = 2\pi L k_{a,g} \frac{t_a - t_g}{\ln \dfrac{b}{D'}} \text{ for cylinders} \qquad (4)$$

where L is the length of the cylinder from which q is lost, and $k_{a,g}$ is the conductivity of the gas at a temperature of $(t_a + t_g)/2$.

Since

$$(Nu)_{d',m} = \frac{q}{S'(t_a - t_g)} \cdot \frac{D'}{k_{a,g}},$$

Equations (3) and (4) may be used to relate the equivalent film diameter b to the Nusselt number. Thus

$$\frac{b}{D'} - 1 = \frac{2}{(Nu)_{d',m} - 2} \text{ for spheres.} \qquad (5)$$

and

$$\frac{b}{D'} - 1 = e^{\frac{2}{(Nu)_{d',m}}} - 1 \text{ for cylinders.} \qquad (6)$$

Inspection of Equations (2), (5), and (6) shows that for spheres and horizontal cylinders

$$\frac{b}{D'} - 1 = \psi(Gr \cdot Pr)_{d',m} \qquad (7)$$

Experimental data will subsequently be presented to show that ψ is the same function for both spheres and horizontal cylinders.

Equations (1), (4), and (6) should apply to vertical as well as horizontal cylinders. However Elenbaas (7) shows that for heat loss by convection from vertical cylinders, Equation (2) should be modified to
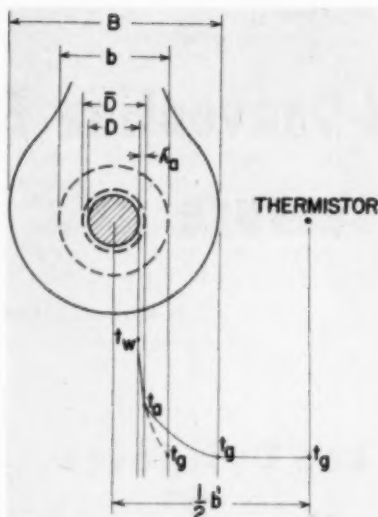

Fig. 1. Schematic diagram for a sphere or horizontal cylinder losing heat to a gas under natural-convection conditions.

$$(Nu)_{d',m} = f_1\left(Gr \cdot Pr \frac{D'}{Z} \right)_{d',m} \qquad (8)$$

where Z is the total length of the heated cylinder. In the present research the length of wire L, from which the heat loss is measured, is only about $\frac{1}{3}$ the total length Z of the heated wire. If a method analogous to that for spheres and horizontal cylinders is used, it follows that for vertical cylinders

$$\frac{b}{D'} - 1 = \phi\left(Gr \cdot Pr \frac{D'}{Z} \right)_{d',m} \qquad (9)$$

Equations (1) to (9) include the effect of free-molecule conduction, always present in heat transfer from solids to gases. However this effect may be ignored if the heat-transfer resistance of the free-molecule region is very small in comparison with that of the convection layer. In such a case Equation (1) is not used; and in Equations (2) through (9) D' is simply replaced by D, t_a by t_w, and the gas properties are evaluated at a temperature of $(t_w + t_g)/2$.

In the present work t_g is measured at a distance of approximately 6 in. from the center of the solid ($\frac{1}{2} b'$ in Figure 1). At low pressures the boundary layer sometimes expands beyond the temperature-measuring element, and so $B > b'$. The temperature gradient then extends beyond the element and t_g is no longer the ambient temperature.

Fortunately, at these low pressures the movement of gas within the boundary layer is apparently so slight that its effect on the rate of heat loss from the solid is negligible. Consequently the ordinary conduction equations may be used to calculate the heat loss

through the essentially stagnant gas from a temperature of t_a at a distance of λ_a from the solid to a temperature of t_g at a distance of $\frac{1}{2} b'$ from the center of the solid. Thus

$$q = 2\pi k_{a,g} \frac{t_a - t_g}{\dfrac{1}{D'} - \dfrac{1}{b'}} \text{ for spheres} \qquad (10)$$

and

$$q = 2\pi L k_{a,g} \frac{t_a - t_g}{\ln \dfrac{b'}{D'}} \text{ for cylinders.} \qquad (11)$$

Since

$$(Nu)_{d,m} = \frac{q}{S(t_w - t_g)} \cdot \frac{D}{k_{w,g}},$$

solving Equation (10) for t_a and substituting this expression for t_a in Equation (1), one obtains

$$\frac{2}{(Nu)_{d,m}} = \frac{2k_{w,g}}{Da\delta} + \frac{k_{w,g}}{k_{a,g}}\left(\frac{D}{D'} - \frac{D}{b'} \right) \text{for spheres} \qquad (12)$$

where

$$\delta = \lambda_o P \sqrt{\frac{273.2}{T_a}}$$

Similarly Equations (11) and (1) yield

$$\frac{2}{(Nu)_{d,m}} = \frac{2k_{w,g}}{Da\delta} + \frac{k_{w,g}}{k_{a,g}} \ln \frac{b'}{D'} \text{ for cylinders.} \qquad (13)$$

Heat is considered to be lost by free-molecule conduction for a distance of one mean free path length from the solid. Equations (2) through (9) consider that this heat is then lost by convection and conduction into a boundary layer and that t_g is measured beyond this layer in the main gas body. At low pressures, when convection currents are slight, the heat lost into the boundary layer can be calculated by the ordinary conduction equations (10) and (11) when t_g is measured inside the layer.

Experimental

The sphere or wire assembly is located centrally in the 18-in.-diam. screen-covered bell jar shown at the right in Figure 2. After the system has been evacuated by the use of an oil diffusion pump in series with a rotary mechanical pump, the desired quantity of dry air, helium (99.8% purity), or argon (99.6% purity) is admitted. The system is then isolated and the gas pressure remains essentially constant during each run.

The 0.00306-in.-wire assembly (Figure 3) is constructed in such a manner that the central wire can be heated by direct current, and the voltage drop across the 5.85-in. wire test section can be measured. Heat loss through

the fine wire potential leads is calculated to be negligible, and end losses are excluded by locating the wire test section in the middle portion of the heated wire.

The heating coil of the 0.312-in.-sphere assembly (Figure 4) occupies a centrally located hole $\frac{1}{8}$-in. diam. and approximately $\frac{1}{4}$ in. deep, which is drilled into the sphere. The coil is saturated with silicone varnish, and the current leads pass through a very small hole in the $\frac{1}{16}$-in.-thick disk-shaped plug, which fits tightly into the $\frac{1}{8}$-in.-diam. hole. The potential leads are silver-soldered to the current leads close to the sphere, and the varnish is baked slowly by passing current through the coil. The thermocouple wires are soft-soldered in a hole drilled into the sphere, and the cold junction is simply made with a drop of soft solder located at the same distance as the Thermistor (2) from the sphere. The sphere assembly is suspended by means of the current leads. Approximate calculations show that lead losses from the sphere may be neglected and that the heat loss through the thermocouple leads does not cause a material difference between the sphere and thermocouple temperatures. A uniform surface temperature is insured by the very high ratio of the metal conductivity to the surface heat-transfer coefficient. The flat surface on top of the sphere is ignored because departure from spherical form is slight. Furthermore, the shape of this region is less critical because of the comparatively low heat loss resulting from the low temperature gradient in the hotter gas at the top of the sphere.

The heating coil of the 1.000-in. sphere, Figure 5, is wound on a rounded spool which fits tightly into a $\frac{3}{8}$-in. hole drilled through the sphere. The assembly is also suspended by current leads which pass through two small slots cut in the top end of the spool.

A resistance box is used to regulate the current supplied from storage batteries through vacuum-sealed brass leads in the base plate of the bell jar to the sphere coil or platinum wire. A Leeds and Northrup type K-2 potentiometer is employed to measure voltages from which the heat loss and temperatures are calculated. The current flow is computed from the voltage drop across a standard resistance in the heating circuit, and measurement of the voltage drop across the platinum wire test section or sphere coil permits calculation of the total heat-loss rate. The resistance-temperature relationship for the wire test section is known by calibration, and a standard Pt-PtRh (10%) thermocouple experimentally checked at 0° and 100° C. is used to determine sphere temperatures.

The gas temperature t_g, Figure 1, is measured approximately 6 in. from the heated solid. For this measurement a small bead (0.015-in.) Thermistor (2), Figure 6, is used in series with a 6,500-ohm resistor through which a feeble current of about 20μa. flows. Even at very low pressures this small current is insufficient to cause a noticeable heating of the Thermistor. The resistance-temperature relationship of the Thermistor is known by calibration, and its position can be changed from outside the bell jar to permit gas-temperature measurements at various
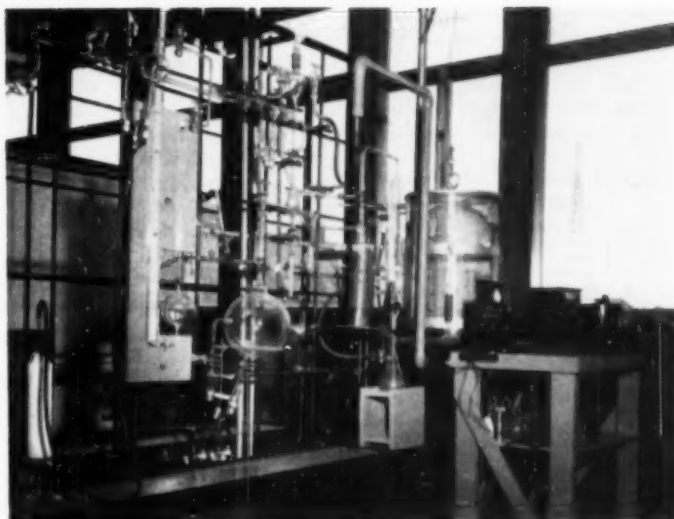

Fig. 2. Photograph of apparatus, showing vacuum bell jar, manometers, and electrical apparatus.
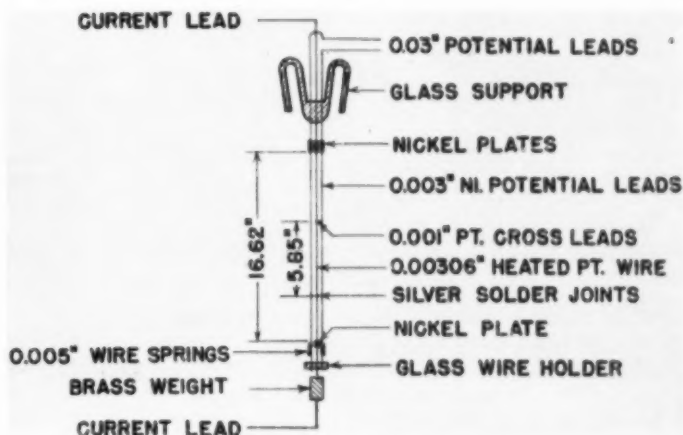

Fig. 3. The 0.00306-in. diam. vertical wire assembly.
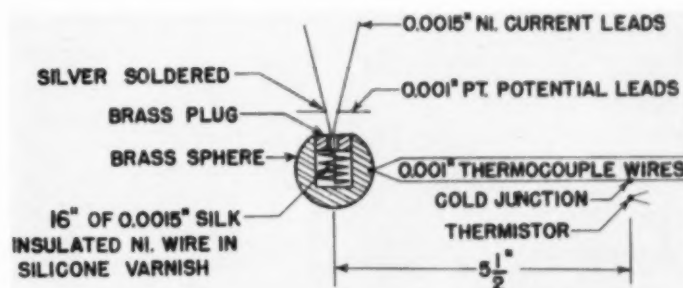

Fig. 4. The 0.312-in. sphere assembly.

distances from the heated solid. The Thermistor is Model 23A obtained from the Western Electric Co.

Radiation losses for the wire test section and the two spheres are experimentally determined by measuring the energy dissipation at a very low pressure near 10^{-5} mm. Hg.

The gas pressure in the bell jar is measured with a closed-end U-tube mercury manometer, a dibutyl phthalate oil manometer, or a McLeod gage, depending upon the pressure level.

Selection of Accommodation Coefficients and Gas Properties

In order to account for the effect of free-molecule conduction, it is necessary to select accommodation coefficients for the different gases on the metal surfaces. The values given in Table 1 were selected after consideration of values reported in the literature (1, 8, 13, 15, 17, 18, 19) for the same or similar systems.

References for the gas physical properties used in the calculations are given in Table 2.

Analysis of Results

The results of testing the validity and range of applicability of the previously developed equations with data and correlations from several sources follow.

Vertical Wires. In Figure 7 natural convection data for vertical wires are correlated by use of Equation (9), which accounts for the effect of free-molecule conduction. For use in Equation (9) t_a is calculated from the free-molecule conduction equation (1), and the equivalent film diameter b is obtained from Equation (4). The data shown from the work of Madden and Piret (15) are for 0.00276- and 0.00988-in.-diam. vertical wires in helium and air at pressures from 1.0 mm. Hg to atmospheric, and with values of $t_w - t_g$ ranging from $10°$ to $65°$ C. In the present work values of $t_w - t_g$ ranging from $10°$ to $165°$ C. are employed with the 0.00306-in. diam. vertical wire in air. In Figure 7 the present data for the large temperature differences are approximately 3% lower than the data for the small temperature differences.

The data of Figure 7 are taken under such conditions that the effect of free-molecule conduction is negligible above pressures of 200 mm. Hg. However this effect lowers the heat-loss rate by about 35% at a pressure of 1 mm. Hg. Figure 7 indicates that Equation (9) does correlate the data well whether the effect of free-molecule conduction is important or not.

The Equation for the solid line of Figure 7 is

$$\frac{b}{D'} - 1 = \frac{4.47}{\left(Gr \cdot Pr \dfrac{D'}{Z}\right)_{d',m}^{0.26}} \quad (14)$$

between $(Gr \cdot Pr D'/Z)_{d,m}$ values of $10^{-4.5}$ and 10^{-11}.

The effect of ignoring free-molecule conduction in correlating natural convection data will now be demonstrated by using correlations which are of a form commonly found in the literature. If Equations (6) and (14) are combined and $b/D' - 1$ is eliminated, there results

$$(Nu)_{d',m} = \frac{2}{\ln\left[1 + \dfrac{4.47}{\therefore \left(Gr \cdot Pr \dfrac{D'}{Z}\right)_{d',m}^{0.26}}\right]}$$
$$(15)$$

Table 1.—Accommodation Coefficients

Gas	Metal Surface	a
air	platinum	0.80
air	brass	0.90
helium	brass	0.50
argon	brass	0.95

This equation, represented by the smooth curve in Figure 8, accounts, as does Equation (14), for the effect of free-molecule conduction and also correlates the convection data for vertical wires.

The circle points of Figure 8 are calculated from the 0.00306-in. vertical wire data, which include experiments at pressures as low as 0.17 mm. Hg where the boundary layer extends beyond the gas-temperature measuring element. For illustrative purposes the effect of free-molecule conduction has been ignored in evaluating Nu and $Gr \cdot Pr \cdot D/Z$. At pressures lower than about 10 mm. Hg, which corresponds to a value of $(Gr \cdot Pr \cdot D/Z)_{d,m}$ of about 10^{-10}, the points are scattered and fall well below the extrapolated curve. In fact, the heat loss in some cases is less than one-fifth the value for ordinary conduction, which illustrates the importance of free-molecule conduction.

The experimental values and those calculated by means of Equation (13) for the case where the boundary layer extends beyond the gas-temperature measuring element are shown in Figure 9. The close agreement supports the use of the ordinary conduction equation (11) for calculating heat transfer with-

Fig. 5. The 1.000-in. sphere assembly.
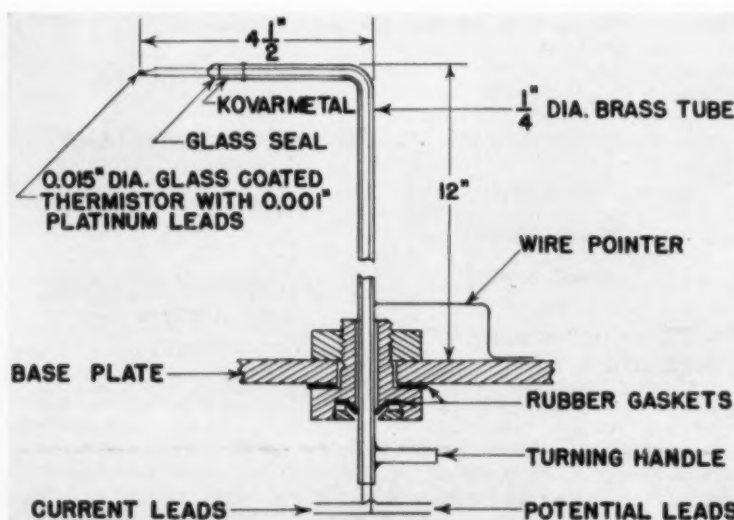
Fig. 6. Thermistor probe assembly.

Table 2.—Sources for Gas Physical Properties

Property	Air		Helium		Argon	
C_p	(12)		$1.252 \frac{cal.}{g.-°C.}$	(13)	$0.125 \frac{cal.}{g.-°C.}$	(13)
μ	(12)		(11)		$\frac{1.91 \sqrt{T}}{1 + \frac{136.6}{T}} \times 10^{-6} \frac{g}{cm.-sec.}$	(14)
k	(12)		(10)		$5/2\ \mu\ C_v$	(13)
λ_a	$\frac{3.46 \times 10^{-6} T_a^{1.25}}{P_{mm.}}$ cm.	(13)	$\frac{2.22 \times 10^{-6} T_a^{1.16}}{P_{mm.}}$ cm.	(13)	$\frac{2.29 \times 10^{-6} T_a^{1.30}}{P_{mm.}}$ cm.	(13)
Λ_a	$16.36 \times 10^{-5} \frac{w.}{sq.cm.-°C.-mm. Hg}$	(4)	$29.35 \times 10^{-5} \frac{w.}{sq.cm.-°C.-mm. Hg}$	(4)	$9.28 \times 10^{-5} \frac{w.}{sq.cm.-°C.-mm. Hg}$	(13)

Fig. 7. Vertical wire data. Gas temperature t_g measured outside boundary layer.

Fig. 8. Data for 0.00306-in. vertical wire, showing effect of ignoring free-molecule conduction.

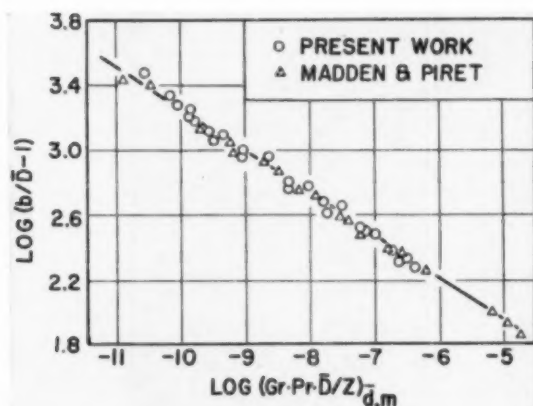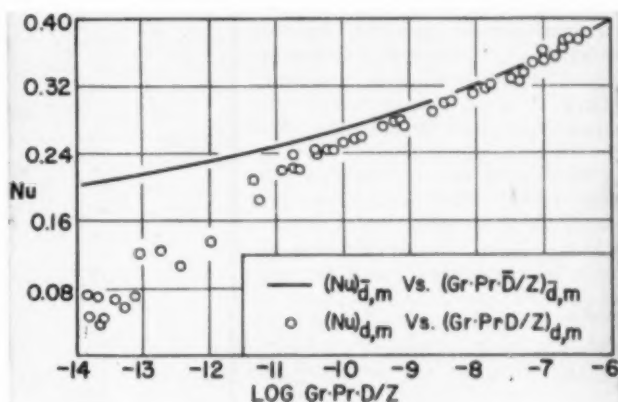in the boundary layer at low pressures. For use in Equation (13) t_a is obtained from the free-molecule conduction equation (1). It should be remembered that Equation (13) can be used only when convection currents within the boundary layer are negligible and t_g is measured inside the layer. For the data shown in Figure 9 values of $\lambda_a/D > 5$ are encountered; that is, the mean-free path length of the gas is more than five times the wire diameter. Values of λ_a/D as high as twenty are reported in the work of Madden and Piret (15).

A few exploratory experiments were also made on temperature distributions in the air surrounding the 0.00306-in. vertical wire. Data for the results shown in Figure 10 are obtained by placing the Thermistor at various distances from the wire. Because of the decrease in convection currents and the corresponding expansion of the boundary layer, the curves for the lower pressures generally lie above the curves for higher

pressures. However the data also illustrate that if the pressure is sufficiently low, the effect of free-molecule conduction is appreciable, and a sharp temperature drop occurs near the wire. This causes a lower temperature distribution in the surrounding gas, as can be seen from the curve for a pressure of 1.17 mm. Hg.

For the case where t represents the gas temperature at a distance of $\frac{1}{8}$ in. from the wire, Figure 11 shows how the ratio of $(t - t_g/t_w - t_g)$ first increases to a maximum and then decreases as the pressure is lowered. Again the decrease is attributed to the effect of free-molecule conduction, which is more pronounced at the very low pressures. The experimental values shown in Figure 11 are believed to be low because of radiation and lead losses from the Thermistor.

Each calculated value of t at a given pressure is obtained by assuming that the experimentally determined heat loss
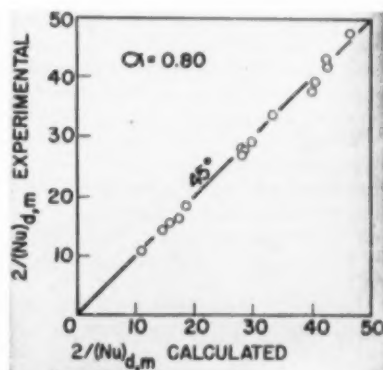
Fig. 9. Data for 0.00306-in. vertical wire in air, showing agreement of experimental with calculated values, Equation (13). Gas temperature t_g measured inside boundary layer.

occurs by free-molecule conduction through a distance of one mean free path length from the wire and by ordinary conduction from this point to a

distance of ⅛ in. from the wire. These calculated values of t are probably quite close to the actual gas temperatures at low pressures. At higher pressures, however, computed values of t are in error because of the appreciable convection currents within the boundary layer which are not accounted for in the calculations. For this reason calculated points at higher pressures are not shown in Figure 11, but the curve passing through the calculated points is extrapolated in order to approximate the actual curve.

Spheres and Horizontal Cylinders. Meager data are available today for natural convection heat transfer from spheres, and all of these data are taken under conditions such that the effect of free-molecule conduction is negligible.

In the present work sphere and horizontal-cylinder data for the case where the gas temperature t_g is measured outside the boundary layer are correlated over a wide range of $(Gr \cdot Pr)_{d',m}$ values from 10^{-7} to 10^{9}. The effect of free-molecule conduction is negligible for all of the 1.000-in.-sphere data, and this effect is significant only for the 0.312-in. sphere below about 1 mm. Hg. At this pressure the boundary layer has expanded beyond the gas-temperature measuring element.

The present data for spheres are plotted in Figure 12 as $(Nu)_{d,m}$ against log $(Gr \cdot Pr)_{d,m}$ for the case where t_g is measured outside the boundary layer. At low values of $(Gr \cdot Pr)_{d,m}$ the value of $(Nu)_{d,m}$ is seen to approach 2, which is the theoretical value for heat loss from spheres by ordinary conduction through a stagnant boundary layer of infinite width. Hence in this region of the correlation for spheres, the natural convection currents within the boundary layer are so slight as to have a negligible effect on the rate of heat loss. If $(Nu)_{d',m}$ and log $(Gr \cdot Pr)_{d',m}$ are used as coordinates, the curve of Figure 12 is expected to correlate natural convection data, whether the effect of free-molecule conduction is significant or not. When this effect is negligible, $(Nu)_{d',m} = (Nu)_{d,m}$ and $(Gr \cdot Pr)_{d',m} = (Gr \cdot Pr)_{d,m}$.

Data from the present work and two other sources (6, 16) are shown in Figure 13, illustrating that $(Nu)_{d,m}$ is not the same function of $(Gr \cdot Pr)_{d,m}$ for both spheres and horizontal cylinders. For high values of $(Gr \cdot Pr)_{d,m}$, however, the percentage difference between $(Nu)_{d,m}$ for spheres and for horizontal cylinders is small. The effect of free-molecule conduction is negligible for all of the data shown in Figure 13.

Equation (7), which utilizes the concept of an equivalent film diameter, is

Fig. 10. Observed temperature distributions for the 0.00306-in. vertical wire.

Fig. 11. Effect of pressure on temperature level near 0.00306-in. vertical wire. $(t_w - t_g)$ = approximately 165° C.

Fig. 12. Data for spheres. Gas temperature t_g measured outside boundary layer. Effect of free-molecule conduction negligible.

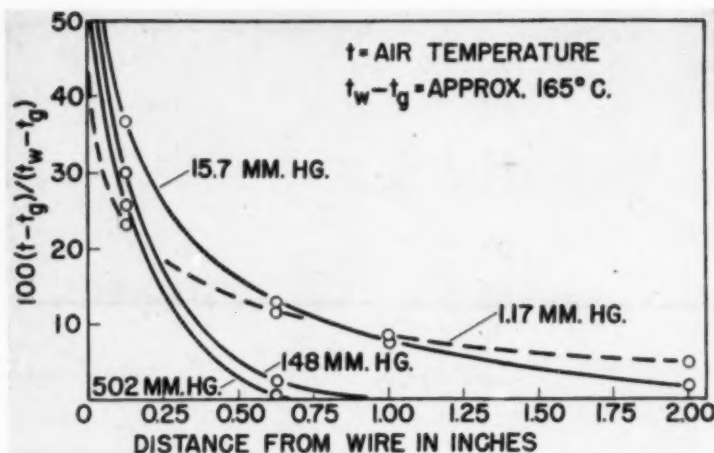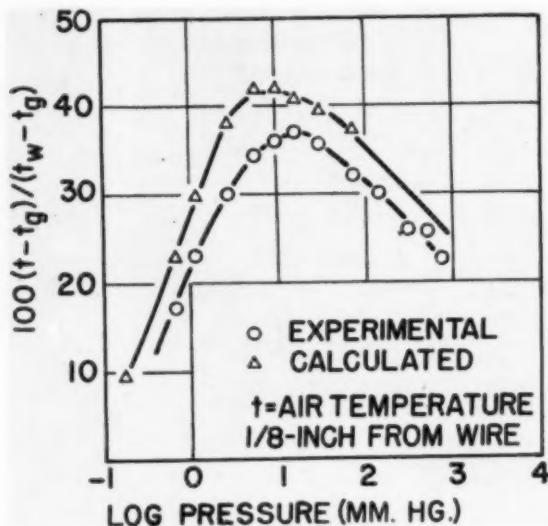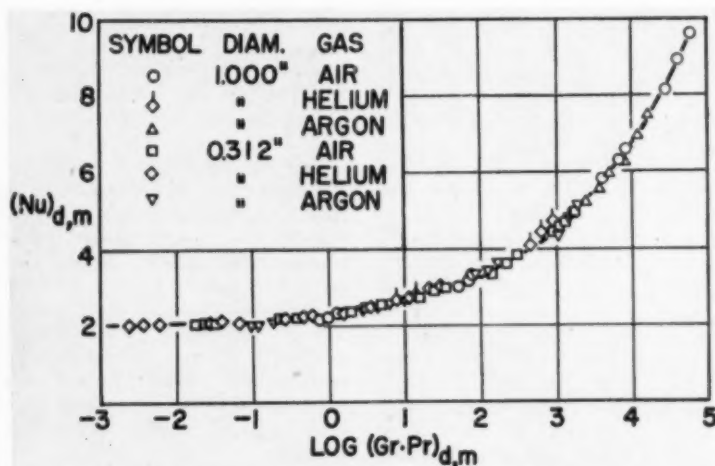successfully used to correlate sphere and horizontal cylinder data from several sources (6, 15, 16). The correlation, Figure 14, extends over a remarkably wide range. It can be seen that the function ψ of Equation (7) is the same for spheres and horizontal cylinders. McAdams' correlation for horizontal cylinders agrees well above a value of $(Gr \cdot Pr)_{d',m} = 10^{1.5}$ with the data shown in Figure 14. Below this value, however, the agreement is not good, and hence McAdams' correlation is not extended to lower values of $(Gr \cdot Pr)_{d',m}$. It is easy, once the effective film diameter b from Figure 14 has been found, to calculate the heat-loss rate from spheres or horizontal cylinders by the use of Equation (4) or (5). This, supplemented by the almost linear relation found, suggests that the correlation shown in Figure 14 be used instead of the classical Nu vs. $Gr \cdot Pr$ relationships for horizontal cylinders and spheres.

The data shown in Figure 14 can be represented by two straight lines intersecting at $(Gr \cdot Pr)_{d',m} = 10^{1.5}$. Equation (7) for spheres and horizontal cylinders becomes

$$\frac{b}{D'} - 1 = \frac{7.09}{\left(Gr \cdot Pr\right)_{d',m}^{0.37}} \quad (16)$$

for values of $(Gr \cdot Pr)_{d',m}$ between 10^{-7} and $10^{1.5}$; and

$$\frac{b}{D'} - 1 = \frac{5.01}{\left(Gr \cdot Pr\right)_{d',m}^{0.26}} \quad (17)$$

for values of $(Gr \cdot Pr)_{d',m}$ between $10^{1.5}$ and 10^9. Above 10^9 turbulent flow occurs in the boundary layer.

Except for the data of Madden and Piret (15) the effect of free-molecule conduction is negligible for all the data shown in Figure 14. However Equations (16) and (17) are expected to be applicable whether this effect is significant or not.

The data shown in Figure 15 are for the 0.312-in. sphere at low pressures when the boundary layer has expanded beyond the gas-temperature measuring element and convection currents are slight. As can be seen, the effect of free-molecule conduction at the lowest pressures causes the value of $2/(Nu)_{d,m}$ to increase to almost two and one-half times the value for ordinary conduction. The close agreement of values calculated by Equation (12) and experimental values supports the use of the free-molecule conduction Equation (1) for heat loss from spheres through a distance of one mean free path length.

The results of measuring a few gas temperatures at different distances from the 0.312-in. sphere are shown in Figure 16. In these experiments the effect of free-molecule conduction is negligible and, as would be expected, at a given distance from the sphere, $(t - t_g)/(t_w - t_g)$ is the same function of $(Gr \cdot Pr)_{d,m}$ for air, helium, and argon.

Use of Heat-Transfer Equations

Combination of Equations (3) and (16) and elimination of the equivalent diameter b yields

$$q = 2\pi D' k_{a,g} \frac{t_a - t_g}{1 - \dfrac{1}{1 + 7.09/\left(Gr \cdot Pr\right)_{d',m}^{0.37}}} \quad (18)$$

This convection equation can be used in conjunction with the free-molecule conduction equation (1) to calculate the heat loss from spheres to gases between values of $(Gr \cdot Pr)_{d',m}$ from 10^{-7} to $10^{1.5}$. Since the rate of heat loss is the same through both regions, the correct rate is obtained when such a value of t_a is selected by trial and error that Equations (18) and (1) yield identical answers. The pairs of equations given in Table 3 for spheres and cylinders may be used in this manner to calculate the heat loss when the effect of free-molecule conduction must be considered.

In the great majority of heat-transfer problems, the effect of free-molecule conduction may be ignored, and one of the more simple convection equations of Table 4 may be used. In fact, these equations can be applied with less than 1% error to spheres and cylinders in any gas at atmospheric pressure if the diameter of the solid is 0.001 in. or greater and the solid temperature is 200° C. or less.

If there is some doubt as to whether the effect of free-molecule conduction on the rate of heat transfer is less than 1%, one should assume that $t_a = t_w - 0.01$ $(t_w - t_g)$ and substitute this value for t_a in the two appropriate equations of Table 3 to calculate a value of q from each equation. If the heat loss as calculated by the free-molecule conduction equation is greater than the loss given by the convection equation, the effect of free-molecule conduction is less than 1% and so may be neglected.

The equations of Tables 3 and 4 are applicable when the gas temperature t_g is measured outside the boundary layer. Although in most situations the width of the boundary layer is unknown, the gas
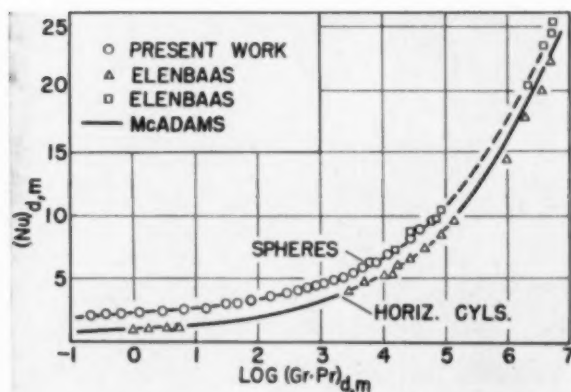

Fig. 13. Data for spheres and horizontal cylinders. Gas temperature t_g measured outside boundary layer. Effect of free-molecule conduction negligible.
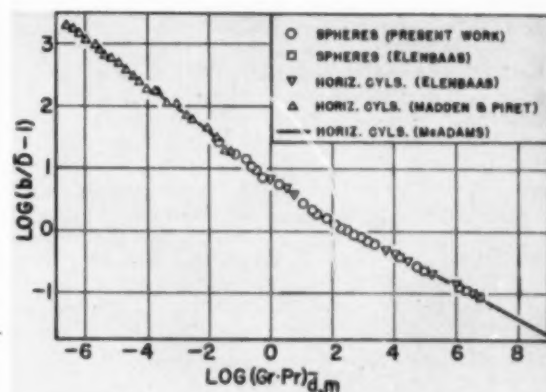

Fig. 14. Heat transfer from spheres and horizontal cylinders to gases under natural-convection conditions. Gas temperature t_g measured outside boundary layer.

Table 3.—Equations for Use When the Effect of Free-Molecule Conduction Must Be Considered

$(Gr\,Pr)_{d',m}$ range	Spheres	Horizontal cylinders
10^{-7} to $10^{1.5}$	$q = 2\pi D' k_{a,g} \dfrac{t_a - t_g}{1 - \dfrac{1}{1 + 7.09/\left(Gr\,Pr\right)_{d',m}^{0.37}}}$	$q = 2\pi L k_{a,g} \dfrac{t_a - t_g}{\ln\left[1 + 7.09/\left(Gr\,Pr\right)_{d',m}^{0.37}\right]}$
	$q = \pi D^2 \Lambda_a P a \sqrt{\dfrac{273.2}{T_a}}(t_w - t_a)$	$q = \pi D L \Lambda_a P a \sqrt{\dfrac{273.2}{T_a}}(t_w - t_a)$
$10^{1.5}$ to 10^{9}	$q = 2\pi D' k_{a,g} \dfrac{t_a - t_g}{1 - \dfrac{1}{1 + 5.01/\left(Gr\,Pr\right)_{d',m}^{0.26}}}$	$q = 2\pi L k_{a,g} \dfrac{t_a - t_g}{\ln\left[1 + 5.01/\left(Gr\,Pr\right)_{d',m}^{0.26}\right]}$
	$q = \pi D^2 \Lambda_a P a \sqrt{\dfrac{273.2}{T_a}}(t_w - t_a)$	$q = \pi D L \Lambda_a P a \sqrt{\dfrac{273.2}{T_a}}(t_w - t_a)$

$\left(Gr\,Pr\,\dfrac{D'}{Z}\right)_{d',m}$ range

Vertical cylinders

10^{-11} to $10^{-4.5}$

$$q = 2\pi L k_{a,g} \dfrac{t_a - t_g}{\ln\left[1 + 4.47/\left(Gr\,Pr\,\dfrac{D'}{Z}\right)_{d',m}^{0.26}\right]}$$

$$q = \pi D L \Lambda_a P a \sqrt{\dfrac{273.2}{T_a}}(t_w - t_a)$$

Table 4.—Equations for Use When the Effect of Free-Molecule Conduction May Be Neglected

$(Gr\,Pr)_{d,m}$ range	Spheres	Horizontal cylinders
10^{-7} to $10^{1.5}$	$q = 2\pi D k_{w,g} \dfrac{t_w - t_g}{1 - \dfrac{1}{1 + 7.09/\left(Gr\,Pr\right)_{d,m}^{0.37}}}$	$q = 2\pi L k_{w,g} \dfrac{t_w - t_g}{\ln\left[1 + 7.09/\left(Gr\,Pr\right)_{d,m}^{0.37}\right]}$
$10^{1.5}$ to 10^{9}	$q = 2\pi D k_{w,g} \dfrac{t_w - t_g}{1 - \dfrac{1}{1 + 5.01/\left(Gr\,Pr\right)_{d,m}^{0.26}}}$	$q = 2\pi L k_{w,g} \dfrac{t_w - t_g}{\ln\left[1 + 5.01/\left(Gr\,Pr\right)_{d,m}^{0.26}\right]}$

$\left(Gr\,Pr\,\dfrac{D}{Z}\right)_{d,m}$ range

Vertical cylinders

10^{-11} to $10^{-4.5}$

$$q = 2\pi L k_{w,g} \dfrac{t_w - t_g}{\ln\left[1 + 4.47/\left(Gr\,Pr\,\dfrac{D}{Z}\right)_{d,m}^{0.26}\right]}$$

temperature can often be measured at a great distance from the solid to insure that t_g be the ambient temperature. In the present work the thickness of the boundary layer is always less than 6 in. at pressures above 5 mm. Hg, and some gas-temperature distribution data are shown in Figures 10 and 16. Relationships resulting from the use of gas-temperature data obtained with probes or by optical methods are needed to determine boundary-layer widths over a wide range of conditions.

At low pressures when the movement of gas within the boundary layer is slight, the point at which t_g is measured may if desired be located inside the boundary layer. The free-molecule conduction equation (1) is then used in conjunction with the ordinary conduction equation (10) for spheres or (11) for cylinders. In the present work convection currents have a negligible effect at pressures lower than 1 mm. Hg. Figure 17 shows that the heat-transfer rates from cylinders in vertical and horizontal positions become identical as the pressure is lowered. This demonstrates experimentally that convection currents decrease in importance at lower pressures.

Application of the equations given in Tables 3 and 4 is demonstrated in the following problem.

Example. What is the predicted rate of heat loss other than radiation from a horizontal brass cylinder 10 ft. long and 0.3 in. diam. if the cylinder at 200° F. is losing heat under natural convection conditions to a large volume of air at 70° F. and at (a) atmospheric pressure? (b) 0.05-mm.-Hg pressure?

For atmospheric pressure it is apparent that the effect of free-molecule conduction may be ignored.

$$(Gr\cdot Pr)_{d,m} = \frac{g\beta\rho^2 D^3(t_w - t_g)}{\mu^2} \cdot \frac{C_p\mu}{k}$$

where $t_w = 200°$ F., $t_g = 70°$ F., $D = 0.025$ ft., $g = 4.17 \times 10^8$ ft./hr.², and the gas properties are evaluated at a temperature of $(200 + 70)/2 = 135°$

F. to give $\beta = 1/(460 + 135) = 0.00168$ ° R.$^{-1}$, $\rho = 0.0667$ lb./cu.ft., $C_p = 0.2403$ B.t.u./lb.(° F.), $\mu = 0.0482$ lb./ft.(hr.), and $k = 0.0167$ B.t.u./hr.(ft.)(° F.).

$$(Gr \cdot Pr)_{d,m} = \frac{(4.17 \times 10^8)(0.00168)(0.0667)^2(0.025)^3(200 - 70)}{(0.0482)^2}$$

$$\cdot \frac{(0.2403)(0.0482)}{(0.0167)} = 1.88 \times 10^3$$

The appropriate equation from Table 3 is

$$q = 2\pi L k_{w,g} \frac{t_w - t_g}{\ln\left[1 + 5.01/\left(Gr \cdot Pr\right)_{d,m}^{0.26}\right]}$$

$$q = (2)(3.14)(10)(0.0167) \frac{(200 - 70)}{2.3 \log[1 + 5.01/(1.88 \times 10^3)^{0.26}]} = 260 \text{ B.t.u./hr.}$$

This demonstrates how easy it is to use the equations of Table 4 when the effect of free-molecule conduction can be ignored.
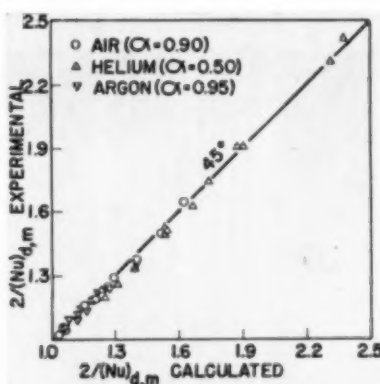

Fig. 15. Data for 0.312-in. sphere, showing agreement of experimental with calculated values, Equation (12). Gas temperature t_g measured inside boundary layer.
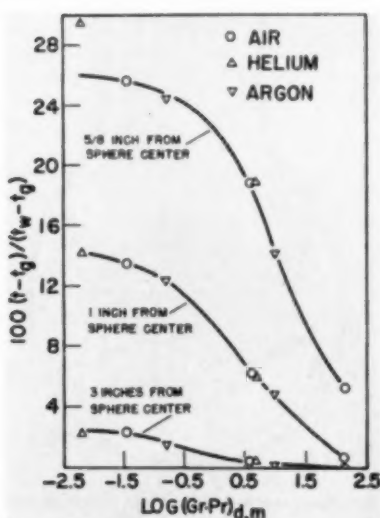

Fig. 16. Correlation of gas temperature data for the 0.312-in. sphere.

For a pressure of 0.05 mm. Hg it is not known whether the effect of free-molecule conduction is significant or not. Using the procedure previously outlined for such situations, one first assumes that $t_a = t_w - 0.01 (t_w - t_g)$.

$$t_a = 200 - 0.01(200 - 70) = 198.7° \text{ F.}$$

$$\lambda_a = \frac{3.46 \times 10^{-6} T_a^{1.28}}{P_{mm.}} \text{ cm.}$$

where

$$T_a = 5/9(198.7 + 460) = 366° \text{ K.}$$

$$\lambda_a = \frac{(3.46)(366)^{1.28}}{0.05} \times 10^{-6}$$

$$= 0.134 \text{ cm.} = 0.0044 \text{ ft.}$$

$$D' = D + 2\lambda_a = 0.025 + 2(0.0044)$$

$$= 0.0338 \text{ ft.}$$

$$(Gr \cdot Pr)_{d',m} = \frac{g\beta\rho^2 D'^3(t_a - t_g)}{\mu^2} \cdot \frac{C_p\mu}{k}$$

The gas properties are evaluated at a temperature of $(t_a + t_g)/2$ to give $(Gr \cdot Pr)_{d',m} = 1.92 \times 10^{-5}$.

The heat-loss rate given by the free-molecule conduction equation is

$$q = \pi D L \Lambda_a P a \sqrt{\frac{273.2}{T_a}} (t_w - t_a)$$

where

$T_a = 366° \text{ K.}$

$\Lambda_a = 16.36 \times 10^{-3} \dfrac{\text{watts}}{\text{cm.}^2 - °\text{ C.} - \text{mm.Hg}}$

$= 28.8 \text{ B.t.u./hr.(ft.}^2)(°\text{ F.})(\text{mm.Hg})$

$a = 0.90$ for air on brass.

$$q = (3.14)(0.025)(10)(28.8)(0.05)(0.9)\sqrt{\frac{273.2}{366.0}}(200 - 198.7)$$

$$= 1.14 \text{ B.t.u./hr.}$$

The heat-loss rate given by the appropriate convection equation is

$$q = 2\pi L k_{a,g} \frac{t_a - t_g}{\ln\left[1 + 7.09\left(Gr \cdot Pr\right)_{d',m}^{0.37}\right]}$$

$$q = (2)(3.14)(10)(0.0166) \frac{(198.7 - 70)}{2.3 \log[1 + 7.09/(1.92 \times 10^{-5})^{0.37}]} = 22.4 \text{ B.t.u./hr.}$$

As the heat-loss rate calculated by the free-molecule conduction equation is less than that for the convection equation, the effect of free-molecule conduction should be considered.

For a value of $t_a = 180°$ F.,

$q = 17.8$ B.t.u./hr. by the free-molecule conduction equation.

$q = 19.0$ B.t.u./hr. by the convection equation.

For a value of $t_a = 178.9°$ F.,

$q = 18.8$ B.t.u./hr. by the free-molecule conduction equation.

$q = 18.8$ B.t.u./hr. by the convection equation.

As the two equations yield identical answers for a value of $t_a = 178.9°$ F., the correct heat-loss rate is 18.8 B.t.u./hr. Calculated values of the heat-transfer coefficients for typical experimental conditions are given in Table 5.

Notation

D = wire or sphere diameter, ft.

L = wire test section length, ft.

Z = total length of heated wire, ft.

B = boundary layer width, ft.

b = equivalent film diameter, ft.

$\frac{1}{2}b'$ = fixed distance from the sphere center or cylinder axis to the point at which the gas temperature t_g is measured, ft.

λ_a = mean free path length of the gas at a temperature of t_a, ft.

$D' = D + 2\lambda_a$ = effective diameter of sphere or cylinder for heat loss by convection, ft.

S = surface area of sphere or cylinder, sq.ft.

S' = effective surface area calculated by using the effective diameter, sq.ft.

t_w = temperature of the solid wire or sphere, ° F.

t_a = temperature of the gas at a distance of λ_a from the solid, ° F.

t_g = temperature of the gas at a distance of $\frac{1}{2} b'$ from the center of the sphere or wire, ° F.

Table 5.—Computed Values of Heat-Transfer Coefficients for the Vertical Wire and Spheres under Natural-Convection Conditions at Subatmospheric Pressures

Solid temperature $= 150°$ F.

Gas temperature $= 70°$ F. at 6 in. from the solid center.

$h = \dfrac{q}{S(t_w - t_g)} =$ B.t.u./hr.(sq.ft.)(° F.)

Pressure mm. Hg	0.00306-in. vert. wire	0.312-in. Sphere			1.000-in. sphere		
	Air	Air	Helium	Argon	Air	Helium	Argon
760	23.4	2.93	9.93	2.08	1.76	4.58	1.24
300	21.4	2.24	8.65	1.57	1.24	3.58	0.87
75	19.1	1.68	7.26	1.16	0.78	2.80	0.55
10	17.5	1.32	7.09	0.90	0.52	2.31	0.35
5.0	14.4	1.29	6.70	0.87	0.44	2.27	0.32
1.0	9.0	1.25	5.75	0.85	0.41	2.04	0.28
0.5	6.8	1.19	4.64	0.79	0.41	1.86	0.27
0.1	2.1	0.89	2.01	0.57	0.36	1.20	0.24

$T_a =$ absolute temperature at a distance of λ_a from the solid wire or sphere, ° K.

$P =$ gas pressure, mm. Hg

$Nu =$ Nusselt number (hD/k)

$Gr =$ Grashof number $(D^3\rho^2 g\beta\Delta t/\mu^2)$

$Pr =$ Prandtl number $(C_p\mu/k)$

$h =$ heat-transfer coefficient, B.t.u./hr.(sq.ft.)(° F.)

$k =$ thermal conductivity of the gas, B.t.u./hr.(ft.)(° F.)

$\rho =$ gas density, lb./cu.ft.

$g =$ acceleration of gravity, ft./hr.²

$\beta =$ coefficient of compressibility, for gases $= 1/T$, ° R.$^{-1}$

$\Delta t =$ temperature difference for heat loss by convection, ° F.

$\mu =$ gas viscosity, lb./ft.(hr.)

$C_p =$ heat capacity of the gas at constant pressure, B.t.u./lb.(° F.)

$q =$ rate of heat loss, other than radiation, B.t.u./hr.

$\Lambda_o =$ free-molecule conductivity of the gas at 0° C., B.t.u./hr.(sq.ft.)(° F.)(mm.Hg)

$\alpha =$ accommodation coefficient

(Other consistent sets of units may be used, but T_a must always be in ° K. when used in the form of the free-molecule conduction equation presented in this work.)

Subscripts:

w, g—indicates that the gas-thermal conductivity is evaluated at a temperature of $(t_w + t_g)/2$.

a, g—indicates that the gas-thermal conductivity is evaluated at a temperature of $(t_a + t_g)/2$.

d, m—indicates that the dimensionless groups are evaluated using D as the diameter, $t_w - t_g$ as the temperature difference, and $(t_w + t_g)/2$ as the temperature at which the gas physical properties are evaluated

d', m—indicates that the dimensionless groups are evaluated using D' as the diameter, $t_a - t_g$ as the temperature difference, and $(t_a + t_g)/2$ as the temperature at which the gas physical properties are evaluated

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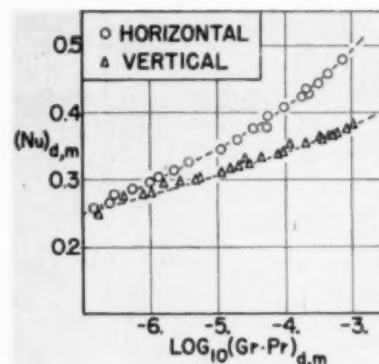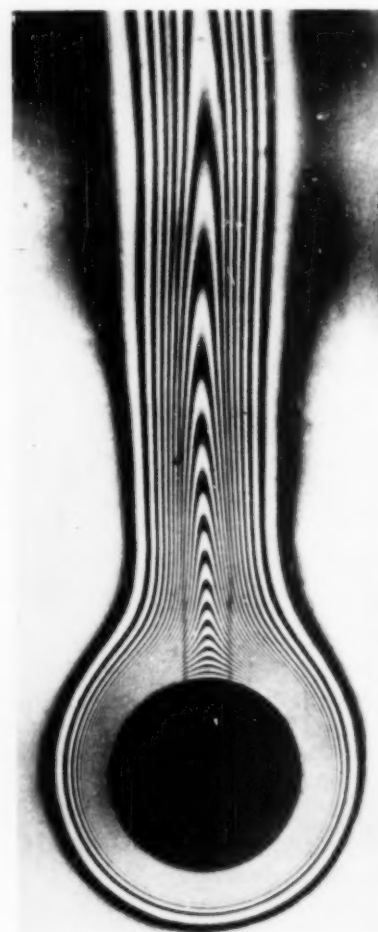19. Weidmann, M. L., and P. R. Trumpler, Trans. Am. Soc. Mech. Engrs., **68**, 57-64 (1946).

Fig. 17. Effect of orientation on heat loss from 0.00276-in. diam. wire. Data of A. J. Madden.

Natural-convection interferometer pattern around a horizontal cylinder

Courtesy E. R. G. Eckert, University of Minnesota.

Free-Convection Mass Transfer at Vertical Plates

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Mass-transfer coefficients for free convection have been evaluated from limiting rates of electrolysis and from rates of dissolution of organic solids. Electrolysis studies involved deposition of copper and silver at vertical electrodes from solutions of copper sulfate and silver perchlorate respectively. Solid plates cast from benzoic and salicylic acids were dissolved into water. Electrode and plate heights varied from ¼ to 5½ in.

Application of existing heat-transfer theories to mass transfer by free convection is outlined, and the various results are compared. A general correlation of the mass-transfer data was obtained which may be expressed by the equation:

$$Nu' = 0.66 \ (ScGr)^{¼}$$

where

Nu' = Nusselt number for mass transfer (average over the plate)

Sc = Schmidt number

Gr = Grashof number

In the form given above the correlation is in good agreement with experimental results over a range of Schmidt numbers from 500 to 80,000 and over a range of Grashof numbers from 10^4 to 10^9.

Mass transfer by free convection is concerned with the spontaneous gravitational movement and mixing which occur when changes in concentration from point to point within a fluid are accompanied by corresponding changes in density. This subject has received relatively little attention in the literature. Evaporation of water from free horizontal surfaces has been interpreted by analogy to heat transfer (3). Boelter (2) has shown that vaporization of water into air flowing vertically and viscously in a wetted wall column may be appreciably influenced by free-convection flow superimposed on the normal viscous-flow pattern. Several studies (1, 14, 16, 20) have been concerned with mass-transfer effects during electrodeposition in unstirred baths. The authors (21) have studied limiting rates of electrolysis in the deposition of copper from sulfuric acid solutions.

The objectives of the present paper are to present (1) a theoretical discussion of free convection at vertical surfaces and (2) experimental data as a basis for comparison of the theories and development of a general correlation for free-convection mass transfer. Two modes of operation have been studied: namely, movement of material toward the interface in electrodeposition of metals and movement of material from the interface in the dissolution of solids. A general interpretation of such processes may be useful in the analysis of other chemical engineering operations.

Theory

MECHANISMS OF MASS TRANSFER

The present discussion will consider physical transfer of ionic or molecular materials unidirected from a body of solution to a vertical solid surface. Consideration will be limited to steady-state processes in which the rate of mass transfer, concentrations of the various species, and all other conditions and properties of the system at any given point in the system remain constant with time.

In the absence of significant temperature gradients and external accelerations other than those resulting from gravitational or electrical forces, transfer may be assumed to occur by the following primary mechanisms 1) migration restricted to movement of ions under a potential gradient in the present systems, that is, electrodeposition of metal, 2) diffusion, and 3) convection. The total rate of transfer of a given component at a particular point within a body of solution per unit area perpendicular to the direction of transfer may be expressed by the equation:

$$N_t = N_m + N_d + N_c \qquad (1)$$

where

N_t = total rate of transfer,
g. ions or g. moles/sq.cm.(sec.)

N_m = rate of migration,
g. ions or g. moles/sq.cm.(sec.)

N_d = rate of diffusion,
g. ions or g. moles/sq.cm.(sec.)

N_c = rate of convection,
g. ions or g. moles/sq.cm.(sec.)

For steady-state processes it is convenient to express the rate of migration as a function of the current flow per unit area:

$$N_m = \frac{tI}{nF} \qquad (2)$$

where

 t = transference number for the given species

 I = current density, amp./sq.cm.

 n = valence charge of the ion

 F = the Faraday, 96,500 amp.-sec./g. equivalent.

The rate of diffusion is given by

$$N_d = -D \frac{dc}{dy} \qquad (3)$$

where

 D = diffusion coefficient, sq.cm./sec.

 c = concentration of diffusing species, g. mole/cu.cm.

 y = distance in the direction of diffusion, cm.

When bulk flow results from volume changes associated with diffusion, the equation must be altered to include this effect (9, 23). For sufficiently dilute solutions equivoluminal diffusion may be assumed with negligible error and Equation (3) is applicable. This is the case for the systems used in the present study.

Convection which involves transport of material by bulk movement of the fluid as a whole, is generally a much more rapid process than molecular diffusion. The rate of transport by convection may be expressed by the relation:

$$N_c = V_y c \qquad (4)$$

where

 V_y = velocity of fluid movement in the y direction, cm./sec.

 c = concentration of transported species, g. mole/cu.cm.

Migration can usually be evaluated from knowledge of the transference number and current flow and thus may be considered separately from the diffusion-convection process. In most liquid systems under moderate density gradients, free-convection mass transfer will deal with simultaneous diffusion and convection in a laminar-flow field. This paper will be limited to these conditions.

In steady-state free convection the main resistance to mass transfer is associated with a relatively narrow region of fluid in the vicinity of the solid-liquid interface, and so the concentration of the bulk solution remains essentially constant. It is convenient

therefore to define the rate of mass transfer from a fluid to a solid in terms of the mass-transfer coefficient for the fluid phase and the concentration difference between the bulk solution and the interface. Thus the local value of the mass-transfer coefficient may be expressed by the equation:

$$N_D = N_d + N_c = k_L(c_o - c_i) \qquad (5)$$

where

 k_L = mass-transfer coefficient, cm./sec.

In general both k_L and c_i may vary from point to point in the vertical direction (x coordinate), and so it is necessary to specify whether k_L is a local point value or an average value over the entire surface area under consideration. In this paper a subscript x, that is, $(k_L)_x$, will denote the local point value; absence of a subscript will denote the average value. A similar convention will be used for other quantities.

In steady-state reactions at electrodes the rate of mass transfer N_D is obtained by subtraction of the migration rate from the total rate of transfer of the species undergoing electrochemical reaction. Thus

$$N_D = \frac{(I-t)I}{nF} = k_L(c_o - c_i) \qquad (6)$$

where

 t = proper average transference number over the mass-transfer region.

The following discussion will consider relations for the prediction of mass-transfer coefficients from system properties. Metal deposition at a vertical cathode will be used as the model for the derivation, although the results obtained are applicable for mass transfer by diffusion and convection in either direction, and for both electrochemical systems and conditions of purely physical mass transfer, as in the dissolution of solids. Application of Equation (6) will be restricted to limiting-current conditions under which transfer occurs at a rate sufficiently great to reduce the interfacial concentration to a value so close to zero that k_L may be evaluated from knowledge of only the mass-transfer rate and c_o. To gain some quantitative insight into the process, the boundary-layer method for heat transfer (6, 5) will be paralleled for mass transfer. This method, which is simpler than use of the Navier-Stokes equations for fluid motion and their counterpart for diffusion and convection, is believed justified since in neither case can a completely rigorous solution be obtained for the situation at hand.

FREE-CONVECTION PROCESS

A vertical-plane cathode of height x and infinite width is considered. One side is insulated and the other is in contact with a solution containing a metal ion to be deposited, the bulk solution in contact with the electrode being assumed infinite in extent. This model can be approximated in practice by a cathode of finite width immersed in a sufficient body of solution so that within the time of an experiment there will be no significant depletion of the bulk solution. The following assumptions are made (1) that at zero current flow the solution is at rest and contains the reacting ion at uniform concentration C_o, (2) that a sufficient excess of inert electrolyte is present to carry most of the current, and (3) that the ions deposited when current flows are transported from the bulk solution to the electrode mainly by diffusional mass transfer. When current is passed through the cell there will be an initial depletion of the metal ions in the region of fluid in immediate contact with the electrode. As the fluid is depleted in metal ions the density is reduced and an upward convective flow of liquid occurs as a result of gravitational forces. This convective flow supplies fresh solution to the electrode and thus improves the mass-transfer process over that which could result from molecular diffusion alone. The layers of solution flowing along the electrode surface undergo greater depletion as they rise to greater heights, and the convection current is continuously increased by movement of additional bulk solution into the depleted regions.

Eventually, if the current or applied potential is kept constant, a steady-state condition will be reached in which ions are supplied to the electrode region by convection at a rate equal to the rate of deposition. The flow pattern in the vicinity of the electrode at steady state is illustrated in Figure 1. A layer of fluid having appreciable vertical components of velocity exists near the surface. This boundary layer increases with thickness in the x direction as indicated in the figure. The exact line of the boundary layer is arbitrary, but it can be assigned a thickness B, which can be defined mathematically by appropriate equations. It may be regarded as the layer of fluid in which the velocity is significantly different from that in the bulk solution. The bulk solution is assumed to be at rest in the present case.

The shape of the velocity profile in the boundary layer at any height x under steady-state free convection has been studied for the analogous case of heat transfer (5, 19) as illustrated in Figure 2. The velocity distribution may
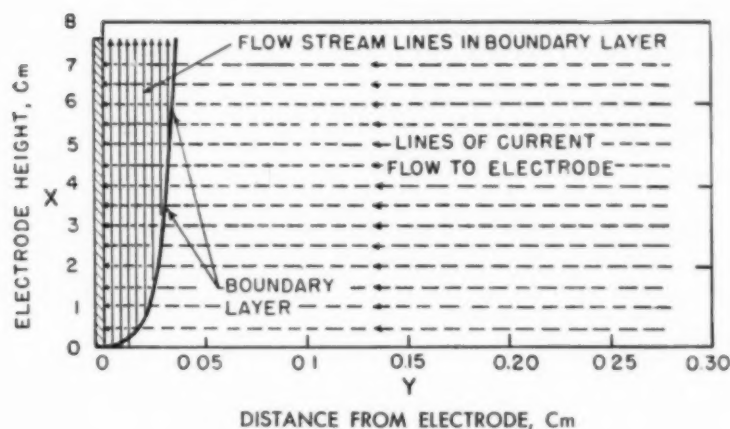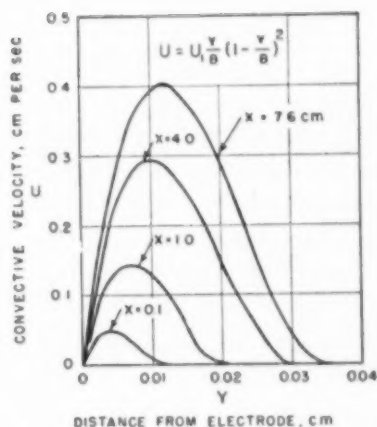
Fig. 1. Boundary layer in free convection.

Fig. 2. Velocity distribution in boundary layer.

be represented approximately by the equation

$$U = U_1 \frac{y}{B} \left(1 - \frac{y}{B} \right)^2 \qquad (7)$$

where

U = velocity at distance y from the electrode

U_1 = a constant

B = boundary-layer thickness.

It can be shown from (7) that the maximum velocity equal to $4/27\,U_1$ occurs at $y = B/3$.

A boundary layer for concentration distribution may also be postulated as the layer in which the concentration is disturbed and thus different from that in the bulk solution. To simplify the present treatment the boundary-layer thickness will be assumed identical for velocity and concentration. If it is assumed that the concentration profile is similar to that obtained for temperature distribution in heat transfer, the concentration within the boundary layer may be represented by the equation

$$\Delta C = \Delta C_o \left(1 - \frac{y}{B} \right)^2 \qquad (8)$$

where

$\Delta C = C_o - C$, $\Delta C_o = C_o - C_e$.

Figure 3 indicates the general shape of the concentration distribution curve.

Derivation of Equations

Analytical expressions to describe the free-convection process will be derived in a manner parallel to that used by Squire (6) and Eckert (5) for heat transfer. In order that this derivation may be used it is necessary to assume that diffusion proceeds according to Equation (3) and that the effect of material transferred to the electrode,

that is, the mass-transfer current in the y direction, makes a negligible contribution to the total momentum transferred in the boundary layer and to the velocity distribution. A more rigorous derivation, besides being extremely complicated, would hardly be justified in view of uncertainties about the basic information necessary for practical use of the result.

Control surfaces formed by parallel planes 12 and 34 of unit width separated by a distance dx and extending a distance $L > B$ through the boundary layer perpendicular to the electrode are shown in Figure 4. The velocity distribution at this value of x is described by Equation (7) and Figure 2 and the concentration distribution by Equation (8) and Figure 3. The change in momentum in the x direction of the fluid which passes upward through the volume element thus formed must be equal to the external forces acting on the volume element as expressed by the following equations.

CHANGE IN MOMENTUM

Since the velocity outside the boundary layer is zero no momentum can enter through plane 24; therefore the change in momentum over the element is given by

Momentum change

$$= \rho' dx \frac{d}{dx} \int_O^L U^2 dy \qquad (9)$$

where ρ' is the average fluid density over the element. Note that Z is taken as unity and omitted from all equations.

GRAVITATIONAL FORCE

If an element of volume $dxdydz$ of density ρ is considered, the buoyant

force relative to a reference density ρ_o has the value

$$F = (\rho - \rho_o)g\,dxdydz$$

where

ρ_o = density at some reference point, i.e., the density of the bulk solution in the present case

ρ = density of the element

g = acceleration of gravity

F = force acting on the element.

For the volume element of Figure 2 the total force is given by:

Buoyant force

$$= dx \int_O^L (\rho - \rho_o)g\,dy. \qquad (10)$$

To facilitate the subsequent integration of Equation (10) it is convenient to express the density as a function of concentration through the specific densification coefficient
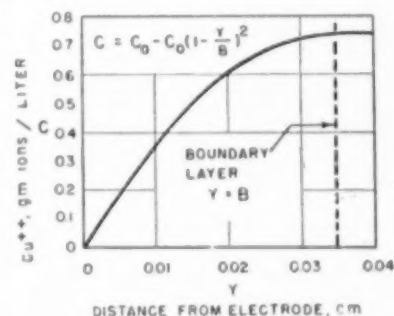

Fig. 3. Concentration distribution in boundary layer.

$$a = \frac{(\rho_o - \rho)}{\rho \Delta C} \qquad (11)$$

where

$$\Delta C = C_o - C$$
$a =$ specific densification coefficient.

If (11) is introduced into (10),

Buoyant force

$$= a\rho' g dx \int_O^L \Delta C dy \qquad (12)$$

where a and ρ' are average values over distance L.

SHEAR FORCE

As a result of the velocity gradient a shear stress acts downward on the fluid element at the wall, and the resulting force is given by:

$$\text{Shear force} = dx \mu_i \left(\frac{dU}{dy}\right)_i \qquad (13)$$

where

$\mu_i =$ coefficient of viscosity at the interface

$\left(\dfrac{dU}{dy}\right)_i =$ velocity gradient at the electrode-solution interface

Combining (10), (12), and (13) gives the momentum equation for the boundary layer:

$$\frac{d}{dx} \int_O^L U^2 dy = ag \int_O^L \Delta C dy$$
$$- \frac{\mu_i}{\rho}\left(\frac{dU}{dy}\right)_i \qquad (14)$$

A corresponding equation for mass transfer may be developed on the basis that the reacting ions must be supplied

Fig. 4. Control surfaces for theoretical derivation.

ELECTRODE HEIGHT
x
DISTANCE FROM ELECTRODE

to the volume element through plane 24 perpendicular to the electrode at a rate equal to the rate of deposition at the electrode plus the change in rate of transfer in the vertical direction through planes 12 and 34 over distance dx. Rate of migration is assumed negligible.

RATE OF TRANSFER THROUGH PLANE 24

Total volume of liquid entering 24

$$= dx \frac{d}{dx} \int_O^L U dy$$

Since this fluid enters the element at concentration C_o, the rate of ion transfer is:

$$\text{Rate} = C_o dx \frac{d}{dx} \int_O^L U dy \text{ g. ions/sec.}$$
$$(15)$$

CHANGE IN RATE OF TRANSPORT THROUGH 12 AND 34 OVER dx

$$= dx \frac{d}{dx} \int_O^L C U dy \text{ g. ions/sec.}$$
$$(16)$$

RATE OF DEPOSITION AT ELECTRODE

Ions move to the electrode by diffusion according to the equation

$$\text{Rate} = dx D_i \left(\frac{dC}{dy}\right)_i = -dx D_i \left(\frac{d\Delta C}{dy}\right)_i$$
$$(17)$$

where

$D_i =$ diffusion coefficient at the electrode-interface

$\left(\dfrac{dc}{dy}\right)_i =$ concentration gradient at the interface.

Combining Equations (15), (16), and (17) gives the mass-transfer equation for the boundary layer

$$\frac{d}{dx} \int_O^L U \Delta C dy = - D_i \left(\frac{d\Delta C}{dy}\right)_i$$
$$(18)$$

Equations (7) and (8) may be substituted in Equations (14) and (18) and the integrals therein evaluated.. To solve the resulting equations further, one must assume that U_1 and B of Equations (7) and (8) vary as power functions of electrode height. Dimensional analysis (5) establishes the exponents of x and leads to the following relations:

$$U_1 = C_1 x^{1/2} \qquad (19)$$
$$B = C_2 x^{1/4} \qquad (20)$$

where

$$C_1 = 5.17 \frac{\mu_i}{\rho'}\left[.952 + \frac{\mu_i}{\rho' D_i}\right]^{-1/2}$$
$$\cdot \left[\frac{ga \Delta C_o \rho'^{+2}}{\mu_i^2}\right]^{1/2} \qquad (21)$$

and

$$C_2 = 3.93\left[.952 + \frac{\mu_i}{\rho' D_i}\right]^{1/4}$$
$$\cdot \left[\frac{ga \Delta C_o \rho'^{+2}}{\mu_i^2}\right]^{-1/4}\left(\frac{\mu_i}{\rho' D_i}\right)^{-1/2}$$
$$(22)$$

The velocity distribution and boundary-layer thickness for any value of x are thus defined by the system of Equations (7), (8), (19), (20), (21), and (22). Figures 1, 2 and 3 are based upon these equations applied to a 0.73 molar $CuSO_4$ solution at limiting current over a 3-in. cathode (in 1.5 molar H_2SO_4).

Since in laminar flow the viscosity and diffusion coefficients are important in establishing the velocity and concentration gradients throughout the entire boundary layer, it seems preferable to evaluate these properties at the average composition of the boundary layer rather than at the interfacial composition, and accordingly μ, ρ, and D, will be written without special designation when average values are implied. $a\Delta C_o$ may be replaced by its equivalent $\rho_o - \rho_i/\rho$. For convenience in writing subsequent equations the following dimensionless groups will be defined and abbreviated as given below:

$$\text{Schmidt number} = Sc = \left(\frac{\mu}{\rho D}\right) \quad (23)$$

$$\text{Grashoff number} = Gr = \frac{g(\rho_o - \rho_i)\rho x^3}{\mu^2}$$
$$(24)$$

Equation (17) may be utilized in Equation (8) to give the rate of mass transfer per unit area at the electrode surface

$$N_D = -D_i\left(\frac{d\Delta C}{dy}\right)_i = \frac{2D \Delta C_o}{B} \qquad (25)$$

where number D_i on the right hand has been replaced by D corresponding to the average composition.

From Equations (5) and (25)

$$(k_L)_x = \frac{2D}{B} \qquad (26)$$

Introducing the value of B from Equations (20) and (22) leads to the result

$$Nu_x' = \frac{(k_L)_x x}{D}$$
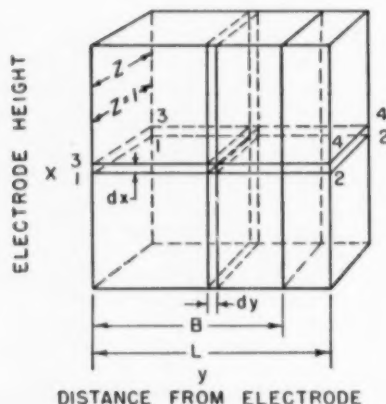$$= 0.508 Sc^{1/2}(0.952 + Sc)^{-1/4}(Gr)^{1/4}$$
$$(27)$$

where

Nu_x' = Nusselt number for mass transfer, analogous to the similar dimensionless group for heat transfer.

If it may be assumed that at the limiting current C_i is reduced to essentially zero over the entire electrode, $(k_L)_x$ varies inversely as the ¼ power of x. By integration over the electrode the average mass-transfer coefficient over height 0 to x can be related to the local value at height x by the equation

$$k_L = 4/3(k_L)_x \qquad (28)$$

When the concentration of the diffusing ion is not negligible or when there may be effects due to simultaneous diffusion of other species, the Nusselt number as a first approximation may be modified to include the film factor analogous to the film-pressure factor for gases (9, 23). For liquid systems this gives the results expressed by Equations (31) to (33)

$$Nu' = \frac{k_L x X_f}{D} \qquad (29)$$

where

X_f = film factor for diffusion of species A in a mixture of species A, B, C, D, etc.

The film factor is defined by the relations

$$(X_f)_A = \frac{(\psi_A - V_A C_A)_{\mathrm{lm.}}}{\psi_A} \qquad (30)$$

$$\psi_A = \frac{N_A V_A}{N_A V_A + N_B V_B + N_C V_C + \ldots} \qquad (31)$$

N_A, N_B, N_C, etc. = diffusion rates of species A, B, C, etc.

V_A, V_B, V_C, etc. = partial volumes of species A, B, C, etc.,cu.cm./g.ion.

$(\psi_A - V_A C_A)_{\mathrm{lm.}}$ = log-mean average value over the diffusion region, i.e., between the bulk solution and the electrode-solution interface.

The preceding relations assume that the partial volumes of the components are additive. For the present case of deposition of species A only from the solution, $\psi_A = 1$ and X_f becomes the log-mean volume fraction of species other than A over the diffusion zone. In case of an electrode reaction liberating an ion of essentially the same partial volume as that which is deposited

and resulting in no net volume change during reaction, X_f becomes unity.

Incorporating Equations (28) and (29) with the right-hand member of (27) gives the general form of the equation for correlation of average mass-transfer coefficients:

$$Nu' = \frac{k_L x X_f}{D}$$
$$= 0.677 \; Sc^{\frac{1}{4}}(0.952 + Sc)^{-\frac{1}{4}}(Gr)^{\frac{1}{4}} \qquad (32)$$

For liquid systems in which 0.952 is negligible compared to Sc,

$$Nu' = 0.677(Sc \cdot Gr)^{\frac{1}{4}} \qquad (33)$$

Alternate Theoretical Results

A solution to the problem of heat transfer in free convection at vertical surfaces was originally developed through the work of Schmidt, Beckmann, and Pohlhausen as summarized in the writings of ten Bosch (18) and Jakob (11). In this treatment the differential equations for fluid motion and conduction are solved in an approximate manner, and subsequent literature has not always made the limitations of the solution clear. In order to evaluate one of the required integrals Pohlhausen made use of Beckmann's result for heat transfer to air, and the result thus obtained is limited to a fluid of Prandtl number similar to that for air, that is, about 0.73. By substitution of the Schmidt number for the Prandtl number the heat-transfer solution may be made applicable to mass transfer. The resulting equation is

$$Nu' = 0.525(ScGr)^{0.25} \qquad (34)$$

A more nearly rigorous solution to the heat-transfer problem has recently been presented by Ostrach in an excellent review of the subject (17). The convection-diffusion equations are developed to give differential equations of the form used by Pohlhausen. By use of an IBM Card Programmed Electronic Calculator solutions of these differential equations were obtained for various values of Prandtl number to give useful tabular functions from which Nusselt numbers and temperature and velocity distributions can easily be obtained. These equations are adaptable to the mass-transfer problem by substitution of Schmidt number for Prandtl number. For the average mass-transfer Nusselt number over a plate of height X_o the result of Ostrach may be expressed as follows:

$$\frac{Nu'}{(Gr)^{\frac{1}{4}}} = 0.943 f(Sc) \qquad (35)$$

where $f(Sc)$ is a function of the Schmidt number, tabulated by Ostrach as the

function $-H'(O)$ of Prandtl number. Equation (32) gives:

$$\frac{Nu'}{(Gr)^{\frac{1}{4}}} = \frac{0.677(Sc)^{\frac{1}{2}}}{(0.952 + Sc)^{\frac{1}{4}}} \qquad (36)$$

Table 1 compares numerical values of Equations (35) and (36) for various Schmidt numbers and corresponding

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Table 1.—Comparison of Theoretical Equations for Mass Transfer by Free Convection

Calculated value of $Nu'/(Gr)^{\frac{1}{4}}$

Schmidt number	Equation (35)	Equation (36)	Equation (34)
0.01	0.0766	0.0648	0.166
0.733	0.4790	0.5087	0.486
1	0.5348	0.5727	0.525
2	0.6757	0.7303	0.625
10	1.103	1.177	0.934
100	2.066	2.091	1.66
1000	3.740	3.806	2.95

---

quantities based on Equation (34). Equations (35) and (36) agree satisfactorily for Schmidt numbers from 0.73 to 1000, the deviation between them never exceeding 10%, and they give almost identical results for the range of high Schmidt numbers which usually prevails in liquid systems. Significant deviation from these latter two equations is obtained with Equation (34); thus the effect of the simplification utilized by Pohlhausen is illustrated.

Alternate equations giving the same general form as Equation (34) but with numerical constants of 0.51 and 0.628 respectively, have been presented by Levich (14) and Keulegan (16). Wagner (20) has developed equations in the manner of the boundary-layer method specifically applicable to the electrodeposition of copper from sulfuric acid solutions. These equations have been discussed in an earlier paper (21).

Limiting-Current Studies

An electrolytic bath contains a vertical-plane cathode upon which metal is being deposited from the corresponding metal ions in solution. If the anode is made of the metal being plated and there are no side reactions, material will be dissolved from the anode at the same rate it is deposited at the cathode; therefore, the average composition of the electrolyte will remain unaltered during the plating process.

The general mass-transfer aspects of the cathode reaction have been presented in the preceding section. For any given rate of current flow, a concentration difference corresponding to the prevailing mass-transfer coefficient will be de-

veloped in the steady state between the bulk solution and cathode-solution interface for the species being deposited. If the current is increased in successive increments in a given cell, the concentration of metal ions at the cathode will be progressively reduced. The limiting rate of current flow is that rate which will reduce the interfacial concentration of the species being deposited sufficiently to increase the electrode polarization to such a high value that successive reactions, for example hydrogen evolution, will be induced. In the systems used in this study the interfacial concentration at the limiting current was reduced to a negligible value compared to the bulk concentration, as evidenced by the measured cathodic polarization. The limiting current is determined experimentally by measuring the total polarization of the working electrode with respect to a suitable reference electrode. As the limiting current is approached a very slight increase in current will be accompanied by a very large increase in polarization, giving a marked plateau in the current-potential curve. From the measured limiting current the mass-transfer coefficient is calculated from Equation (6). With sufficient excess of inert electrolyte the transference number of the deposited species may be reduced to a negligible value. This general technique for determination of mass-transfer coefficients has been described in detail (21). Lin, Denton, Gaskill and Putnam (15) have utilized the method in forced-convection studies.

Apparatus and Materials

The apparatus consisted of an electrolytic cell for deposition of copper from copper sulfate-sulfuric acid solutions and for deposition of silver from silver perchlorate-perchloric acid solutions. Auxiliary equipment was provided for measurement of total current and cathode potential relative to the bulk solution in the cell. Figure 5 is a schematic diagram of the apparatus as arranged for copper plating.

The cell was a rectangular Lucite container 7.6 cm. wide, 10 cm. high, and 10.2 cm. long. A plate of the metal being deposited formed one end wall and served as anode. The cathodes were placed in Lucite mountings in the end wall of the cell opposite the anode. These mountings permitted use of cathodes of four different heights: 0.634 cm., 2.54 cm., 3.75 cm., and 7.6 cm., and facilitated changing of electrodes for repetition of the experiments. All cathodes were of width equal to the inner dimension of the cell, that is, 7.6 cm. The cathodes were insulated with glyptal lacquer so that only the side facing the anode conducted current. A contact screw through the Lucite holder was used to complete the electrical circuit. Constant source of direct current was provided by storage batteries. A fresh electrode was used for each limiting current determination, each electrode
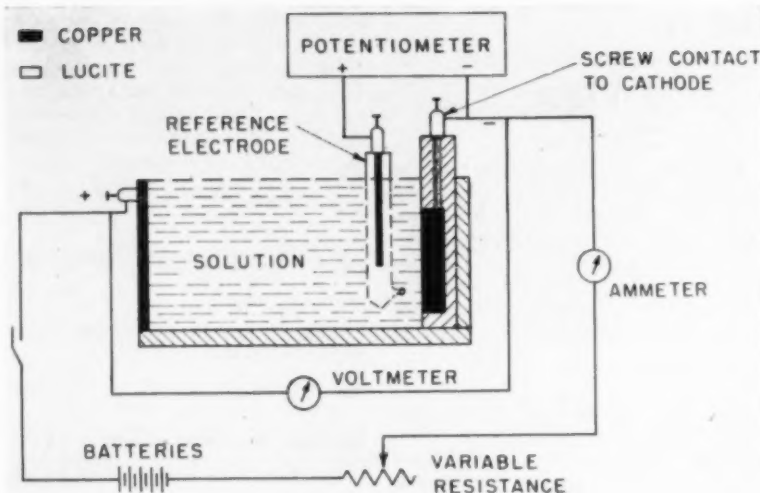
Fig. 5. Cell and circuit diagram.

having been abrased, polished, and preplated by a standard procedure to assure uniformity of surface properties. Care was taken to obtain smooth alignment of the cathode surface with the vertical cell wall formed by the Lucite holder.

As reference electrode a rod of the same metal as the cathode was immersed in a solution of the same composition as the bulk liquid in the cell. A capillary located in the corner of the cell at the center line of the cathode connected the reference electrode to the system.

Fifteen different solutions of CuSO₄ ranging in molarity from about 0.01M to 0.74M in approximately 1.5 molar H₂SO₄ were studied. In another series of experiments copper was plated from solutions containing glycerol in amounts ranging from 3.28 to 6.38 moles/liter in approximately 1.5 molar H₂SO₄. A detailed description of the copper-deposition studies has been reported elsewhere (21).

Seven solutions of AgClO₄, ranging in molarity from 0.096 to 1.17 moles in approximately 1.5 molar HClO₄, were used in the silver-plating experiments.

Procedure

With the electrodes in place the cell was filled with liquid to a depth of 10 cm., completely covering the cathode in all cases. Current was then passed through the cell and increased by small increments at 1-min. intervals until the limiting current was obtained and then usually increased further to the point of hydrogen evolution. From the plateau in the current-potential curve the limiting current was evaluated. Temperature measurements were made during the runs for subsequent evaluation of liquid properties.

Results

Figure 6 is a typical current-potential curve indicating a limiting current density of 56.5 ma./sq.cm. Similar measurements were made on all systems. Experimental data for the silver perchlorate systems are presented in Table 2.

CORRELATION OF RESULTS

Average mass-transfer coefficients corresponding to each limiting current density were calculated by Equation (6). The transference number for the metal ion was assumed to be the arithmetic mean of the values for the bulk solution and the interfacial concentration as estimated from ionic mobilities at infinite dilution. Since c_i was assumed negligible compared to c_o, the transference number was taken as one half the value in the bulk solution. In the absence of a rigorous theory for transference for the present process, this procedure seemed justified. Average transference numbers thus estimated did not exceed 0.03 in the copper systems and 0.05 in the silver systems for even the most concentrated solutions.

Migration effects associated with the cathode reaction caused a net movement of acid toward the electrode so that a steady-state condition was obtained when the rate of mass transfer of acid away from the electrode equaled the rate of its inward migration. The resulting increase in acid concentration at the interface is given by the equation (21):

$$\Delta c_a = \Delta c_o \left[\frac{D_a}{D_s} \right]^{\frac{3}{4}} \frac{t_H^+}{(1-t_m^+)} \qquad (37)$$

where

Δc_a = increase in acid concentration over that in the bulk solution, moles/cu.cm.

Δc_o = decrease in metal ion concentration from that in the bulk solution, g. ions/cu.cm.

Table 2.—Experimental Data and Results for Deposition of Silver from AgClO₄-HClO₄ Solutions

Run No.	Electrode Height in.	AgClO₄ molarity	HClO₄ molarity	Limiting Current Density ma/sq.cm.	Mass Transfer Coefficient cm./sec. $\times 10^3$	Temp. °C.	Average Viscosity centipoise	Average Density $g.$/cu.cm.	Average Diffusion Coefficient sq.cm./sec. $\times 10^5$	ΔC_a mole/liter[1,2,3]	$\rho_o - \rho_i$ $g.$/cu.cm.	Nu'	Sc	Gr $\times 10^{-9}$
1a	0.25	0.0964	1.533	11.8	1.26	24.7	0.862	1.092	2.03	0.055	0.0115	39.5	416	0.0374
2a	0.25	0.1938	1.507	28.2	1.50	25.3	0.826	1.099	2.04	0.1101	0.0238	46.6	406	0.0795
3a	0.25	0.3390	1.508	58.6	1.76	24.2	0.844	1.113	1.95	0.1913	0.0423	57.6	434	0.1340
4a	0.25	0.4848	1.506	93.1	1.95	24.8	0.828	1.126	1.95	0.2717	0.0605	63.5	426	0.1966
5a	0.25	0.6745	1.510	140.0	2.09	23.6	0.844	1.145	1.84	0.3743	0.0825	72.0	458	0.2538
1b	1.00	0.09647	1.533	8.42	0.900	24.7	0.842	1.092	2.03	0.0590	0.0113	112.0	416	2.344
2b	1.00	0.1928	1.510	19.8	1.05	24.5	0.843	1.100	2.00	0.1095	0.0237	134.2	423	4.870
3b	1.00	0.3392	1.510	39.6	1.19	24.4	0.840	1.113	2.00	0.1911	0.0424	154.6	430	8.658
4b	1.00	0.4833	1.512	59.6	1.25	25.0	0.825	1.126	1.95	0.2702	0.0604	162.6	423	12.642
5b	1.00	0.6750	1.520	97.4	1.45	24.4	0.830	1.145	1.86	0.3717	0.0827	198.3	446	16.83
6b	1.00	0.9402	1.518	147.1	1.56	26.2	0.797	1.169	1.87	0.5112	0.1133	211.2	425	24.51
7b	1.00	1.168	1.516	200.1	1.70	24.9	0.816	1.189	1.77	0.6306	0.1400	243.2	461	28.39
1c	2.955	0.09660	1.535	6.66	0.711	24.6	0.843	1.092	2.02	0.0551	0.0116	264.3	417	61.78
2c	2.955	0.1906	1.515	14.9	0.804	24.3	0.846	1.100	1.98	0.1081	0.0234	305.2	428	123.4
3c	2.955	0.3394	1.514	28.9	0.870	24.4	0.840	1.113	1.96	0.1912	0.0424	333.9	430	223.5
4c	2.955	0.4725	1.528	49.3	1.06	25.4	0.818	1.126	1.97	0.2647	0.0591	403.1	415	324.8
5c	2.955	0.6645	1.531	72.4	1.10	24.8	0.823	1.144	1.89	0.3670	0.0814	434.7	435	435.4
6c	2.955	0.9382	1.528	118.3	1.26	26.2	0.796	1.169	1.89	0.5132	0.1129	498.7	421	631.0
7c	2.955	1.160	1.511	164.8	1.41	26.0	0.799	1.188	1.83	0.6282	0.1390	577.2	437	759.8

Notes:

1 based on Equation (37).   2 $\frac{D_a \mu}{T}$ for 1.5 M HClO₄ $= 1.04 \times 10^{-7}$.   3 Transference numbers of H⁺ varied from 0.80 to 0.83.

D_a = average diffusion coefficient of the acid over the mass transfer film, sq.cm./sec.

D_s = average diffusion coefficient of the salt, sq.cm./sec.

t_m^+ = average transference number of the metal ion being deposited

t_H^+ = average transference number of the hydrogen ion.

Effective diffusion coefficients for the metal ions were assumed to be those for the corresponding salt formed from the single anion present. Anions and hydrogen ion were assumed to diffuse as the corresponding acid since these were the predominant species. Diffusion coefficients for sulfuric acid in water were based on the data of James, Hollingshead, and Gordon (12 and 8) and Thovert (10 and 13), and values for copper sulfate in sulfuric acid were based on experiments of Gordon, et al. (12). Diffusion coefficients required for the silver perchlorate systems were measured in a diaphragm cell (4). These available diffusion data were corrected for the viscosities and temperatures prevailing in the runs by assuming the group $D\mu/T$ to be a function of ionic strength.

Viscosities were measured for all solutions with an Ostwalt viscosimeter over the range of composition and temperature of interest. Densities were measured over the necessary range of compositions and temperatures with a special pycnometer of large volume. Based on a values for each species determined as a function of concentration and temperature as defined in Equation (11), densities of all solutions and den-

sity differences between the bulk solution and the electrode were calculated for all experiments.

By the use of mass-transfer coefficients and property values determined as discussed above, Nusselt, Schmidt, and Grashof numbers were calculated for each experiment. Table 2 gives these results for the silver perchlorate runs. Plots of the Nusselt number

versus the Schmidt-Grashof number product for the various systems are shown in Figures 7, 8, and 9. The lines through the data points were placed by calculating the average numerical constant in Equation (33) for all of the copper systems and for the silver systems. It is believed that results for these two systems are in agreement within limitations imposed by experi-

Fig. 6. Typical current potential curve.

3 in. CATHODE
0.732 m CuSO₄
1.484 m H₂SO₄
○ RUN A
△ RUN B
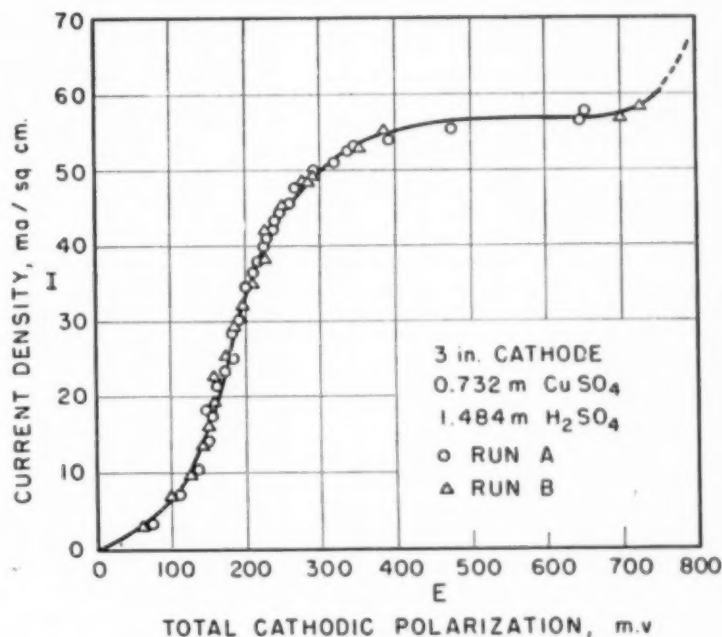
mental error and uncertainties in physi-
cal data.

Dissolution of Organic Solids

This section will describe experiments
made in the dissolution of benzoic and
salicylic acids under free-convection
conditions. The solids were cast into
the form of smooth vertical plates and
immersed in distilled water. From ob-
servation of the rate of weight loss as
the solid passed into solution, mass-
transfer coefficients were calculated.

Materials and Apparatus

The melting points of benzoic and salicylic
acid were found to agree satisfactorily with the
manufacturers' specifications and with accepted
values in the literature. To simulate the physical
arrangement used in the electrolysis experiments
the melted acids were poured into molds to form
a rectangular shape which would dissolve from
one side only. The molds were aluminum plates
into which were milled depressions of about
⅛-in. depth to hold the solid. The plates were
of sufficient size to be readily immersed in liquid
and supported in a vertical position. The cast-
ings thus made presented surfaces of solid acid
approximately 3 in. in width and of the following
range of heights: 1 in., 2 in., 3 in. and 5½ in.
The 1-, 2- and 3-in. plates were arranged at one
end of the Lucite cell, which had been used
previously for electrolysis studies. The 5½-in.
plates were placed in a large glass jar. Figures
10 and 11 show typical molds containing the
solids and the arrangement of the molds in their
containers.

The runs were conducted in an air bath main-
tained at approximately 25° C. To avoid vibra-
tion from mechanical stirring, free-convection
circulation was established in the bath by means
of water-cooled coils at the top and electrical
heaters at the bottom. Temperature was meas-
ured with a thermometer placed in the bath at
approximately the same elevation as the dissolv-
ing solids.

Procedure

The plates of solid were prepared as follows.
Molten acid was poured slowly into a polished,
cleaned, and preheated mold and the system al-
lowed to cool slowly in a hood. A stainless steel
plate heated to slightly above the melting point
of the solid was passed over the mold to smooth
off any protruding material. Final smoothing
was done with a sharp razor blade until the
solid was exactly flush with the surface of the
mold and excess solid around the edges had
been removed. The molds were finally rinsed
with distilled water and dried in a desiccator.

Containers for the molds filled with distilled
water were placed in the air bath and allowed
to attain the prevailing constant temperature.
The finished plates at approximately the same
temperature as the air bath were weighed and
placed carefully in their respective containers
with the surface of the cast solid completely
immersed in water. Air bubbles which occasion-
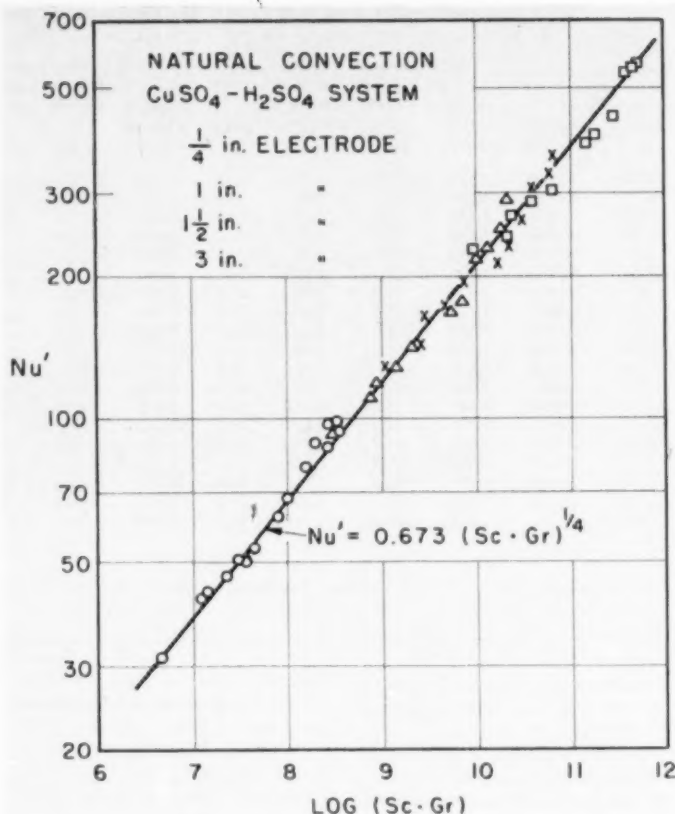
Fig. 7. Correlation of data for copper deposition.
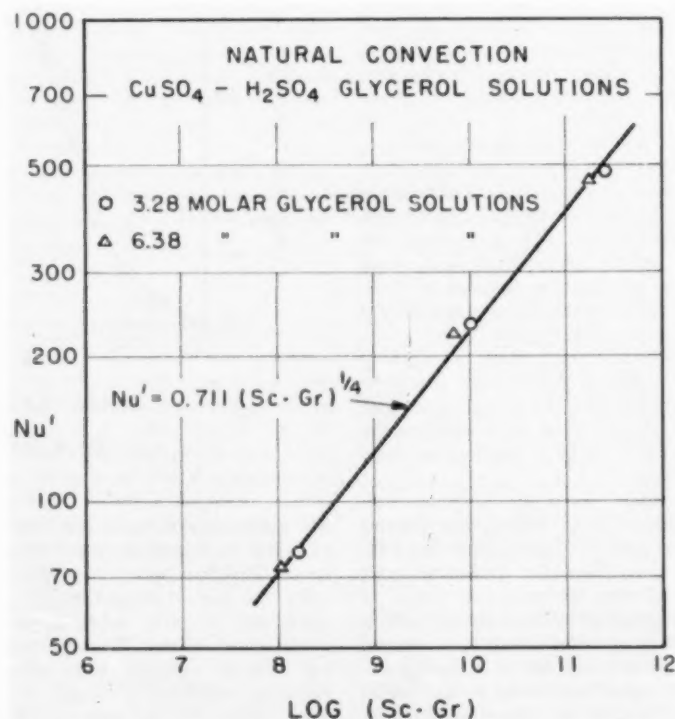
Fig. 8. Copper deposition from glycerol solutions.
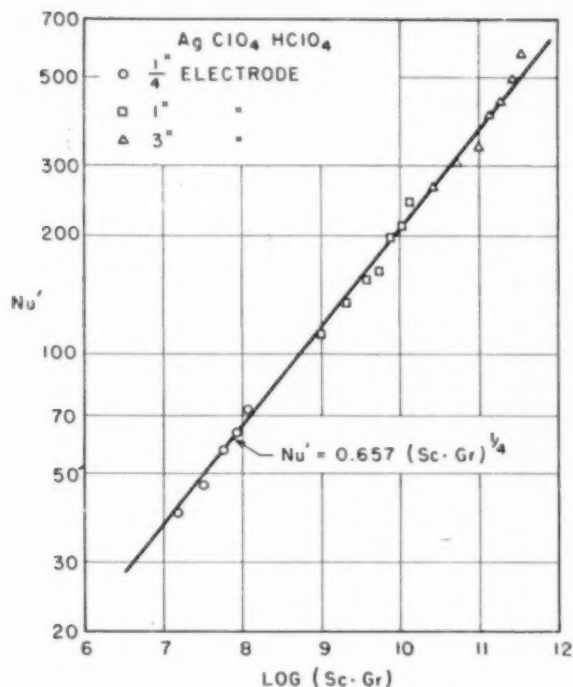
Fig. 9. Correlation of data for silver deposition.

Fig. 10. Molds containing plates cast from benzoic acid.

Fig. 11. Apparatus for dissolution of solids.

ally adhered to the surface were gently removed with a glass rod. The plates were left in the apparatus for periods ranging from 3 to 12 hr. These time intervals were sufficiently long to dissolve an easily weighable quantity of material and also to make negligible the effects of initial disturbance of the liquid as the plates were immersed. The previous electrochemical studies indicated that essentially steady-state conditions were reached in 1 or 2 min. in free convection at electrodes, and it seemed reasonable therefore to assume that time for attainment of steady state in the present systems was negligible compared to the duration of the runs. At the conclusion of the run the plates were removed, wiped free of water, dried in a desiccator, and weighed.

Results

Essential experimental data are summarized in Tables 3 and 4.

Average rates of dissolution were calculated from the total time of the experiment and the total weight of solid which had passed into solution. Since the volume of liquid was insufficient to maintain a completely negligible concentration of acid in the bulk fluid region, it was necessary to compute an average concentration difference on which to base the mass-transfer coefficient as defined by Equation (5). This was done by assuming the dissolved solid to be uniformly distributed throughout the fluid and using a log-mean average based on concentrations at the beginning and end of the run.

This assumption could not lead to serious error in the mass-transfer coefficients since the final concentration of acid in the bulk solution for the various runs ranged from 5% to 15% of the concentration at the interface, and the log-mean average concentration difference was in general only about 5% lower than that which would have been obtained if there had been no increase in acid concentration of the bulk solution. The mass-transfer coefficient was thus calculated from the equations:

$$k_L = \frac{N_D}{\Delta c_{lm}} \qquad (39)$$

$$\Delta c_{lm} = \frac{(c_i - c_1) - (c_i - c_2)}{\ln \frac{(c_i - c_1)}{(c_i - c_2)}} \qquad (40)$$

where

N_D = average rate of acid dissolution per unit area of exposed surface, g.mole/sq.cm.(sec.)

Δc_{lm} = log-mean average concentration difference for mass transfer, g.mole/cu.cm.

c_i = concentration of acid at the interface, i.e., solubility at the prevailing temperature

c_1 = acid concentration in bulk liquid at start of run, zero in the present case

c_2 = acid concentration in bulk liquid at end of run
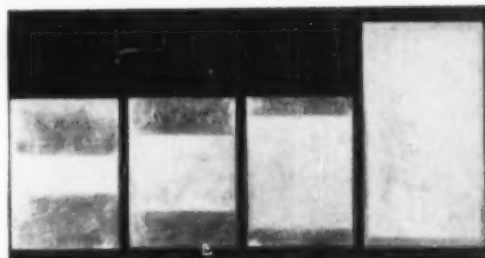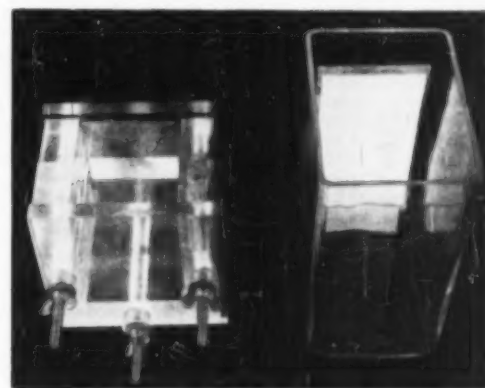
Densities, concentrations, and viscosities of saturated solutions of the organic acids were measured, and the results as applied to each run are summarized in Tables 3 and 4.

Diffusion coefficients were determined for diffusion of benzoic and salicylic acids into pure water in a diaphragm cell (4). Temperature and concentration variations were estimated on the assumption that $D\mu/T$ for each substance was a constant over the small ranges of concentration and temperature involved in the studies (22).

By the various data outlined above, Nusselt, Schmidt, and Grashof groups were calculated for each experiment, these results appearing in Tables 3 and 4 and Figures 12 and 13. Best lines of 0.25 slope on the log-log plot were passed through the data corresponding to numerical constants—in Equation (33) of 0.673 and 0.603 for benzoic and salicylic acids respectively.

Conclusions

All the data for the various systems have been grouped together to establish the general correlation shown in Figure 14. The line through the data corresponds to an over-all average constant in Equation 33 of 0.66 for the four systems, taken simply as the average of the five constants for the individual systems. This procedure was considered preferable to placing a best average lined base on consideration of

Table 3.—Data for Dissolution of Benzoic Acid[1,2]

Run No.	Temp. °C.	Saturated solution concentration g. mole liter	Acid concentration at end of run g. mole liter	Time of run sec. $\times 10^{-3}$	$k_L \times 10^3$, cm./sec.	Nu'	Gr $\times 10^{-6}$	Sc	Plate height inches
5a	25.25	0.02766	0.00410	24.02	0.253	68.7	0.1296	959	1.000
8a	25.38	0.02777	0.00340	23.29	0.255	68.7	0.1343	942	1.000
9a	25.10	0.02754	0.00400	23.11	0.257	69.7	0.1289	954	1.000
10a	25.50	0.02788	0.00399	23.48	0.249	66.9	0.1347	937	1.000
12a	25.05	0.02750	0.00250	13.55	0.266	72.2	0.1320	956	1.000
13a	25.00	0.02746	0.00222	12.11	0.263	71.6	0.1319	959	1.000
14a	24.95	0.02742	0.00273	15.50	0.256	69.8	0.1300	961	1.000
15a	25.00	0.02746	0.00285	16.22	0.256	69.5	0.1302	959	1.000
1b	25.10	0.02754	0.00642	20.48	0.244	132.4	1.031	954	2.000
3b	25.15	0.02758	0.00395	13.46	0.216	117.2	0.9847	952	2.000
5b	25.30	0.02770	0.00398	12.55	0.233	125.7	1.043	945	2.000
6b	25.30	0.02770	0.00354	11.05	0.233	125.6	1.054	945	2.000
7b	24.70	0.02738	0.00311	10.23	0.222	120.9	1.026	963	2.000
3c	25.20	0.02762	0.00733	19.89	0.195	158.7	3.276	950	3.003
4c	25.00	0.02746	0.00687	18.27	0.199	162.3	3.230	960	3.003
6c	24.95	0.02742	0.00170	9.82	0.196	160.3	3.554	961	3.003
8c	25.35	0.02775	0.00166	8.95	0.207	167.3	3.712	943	3.003
9c	25.05	0.02750	0.00165	9.15	0.204	166.3	3.639	956	3.003
10c	25.35	0.02775	0.00130	7.32	0.196	159.1	3.756	943	3.003
11c	24.85	0.02734	0.00229	13.76	0.191	156.5	3.480	953	3.003
12c	24.85	0.02734	0.00194	11.67	0.190	156.7	3.518	965	3.003
1d	24.88	0.02736	0.00449	19.21	0.175	262.5	20.89	963	5.500
2d	25.05	0.02750	0.00458	19.60	0.172	256.9	21.23	956	5.500
3d	24.45	0.02786	0.00347	14.27	0.174	258.4	22.69	939	5.500
4d	25.35	0.02775	0.00196	7.96	0.172	255.3	23.04	944	5.500

[1] Properties of Saturated Solution at 25° C.: $a = 25.0$ cu.cm./g. mole, $\mu = 0.894$ centipoise, $D = 0.935$ sq.cm./sec.
[2] Plate widths as follows: Series a, 2.74 in.; Series b, 2.756 in.; Series c, 2.744 in.; Series d, 3.003 in.

Table 4.—Data for Dissolution of Salicylic Acid

Run No.	Temp. °C.	Saturated solution concentration g. mole liter	Acid concentration at end of run g. mole liter	Time of run sec. $\times 10^{-3}$	$k_L \times 10^3$, cm./sec.	Nu'	Gr $\times 10^{-6}$	Sc	Plate height inches
1a	25.05	0.01630	0.00206	20.14	0.255	59.0	0.1246	815.0	1.000
2a	25.05	0.01630	0.00194	19.04	0.252	58.4	0.1251	815.0	1.000
3a	24.90	0.01618	0.00181	18.45	0.259	60.1	0.1237	820.7	1.000
4a	25.35	0.01652	0.00172	15.90	0.263	61.1	0.1299	812.7	1.000
5a	25.20	0.01641	0.00159	15.20	0.255	58.8	0.1285	809.4	1.000
6a	25.00	0.01626	0.00142	13.63	0.267	61.9	0.1265	818.2	1.000
1b	25.15	0.01637	0.00276	15.34	0.226	104.4	0.9877	811.0	2.000
2b	25.25	0.01645	0.00276	15.27	0.226	104.3	0.9944	807.1	2.000
3b	25.15	0.01637	0.00253	14.17	0.223	102.9	0.9953	811.0	2.000
4b	25.15	0.01637	0.00221	12.45	0.220	101.5	1.006	811.0	2.000
5b	25.45	0.01660	0.00227	12.53	0.221	101.5	1.031	800.0	2.000
6b	25.05	0.01630	0.00187	9.91	0.232	107.6	1.003	815.0	2.000
7b	25.15	0.01637	0.00172	9.13	0.229	105.7	1.022	811.0	2.000
4c	25.55	0.01668	0.00106	9.90	0.199	137.	3.620	796.2	3.003
5c	25.20	0.01641	0.00095	9.90	0.199	135.4	3.620	809.4	3.003
6c	25.15	0.01637	0.00086	8.21	0.197	136.4	3.516	811.0	3.003
1d	25.15	0.01637	0.00167	11.30	0.178	226.2	21.42	811.0	5.500
2d	25.10	0.01633	0.00165	11.55	0.172	219.7	21.26	813.4	5.500
3d	25.20	0.01641	0.00157	10.83	0.173	220.5	21.53	809.4	5.500
4d	25.45	0.01660	0.00186	12.45	0.169	213.2	21.87	800.0	5.500
5d	25.30	0.01649	0.00162	11.38	0.170	215.4	21.72	805.4	5.500

[1] Properties of Saturated Solution at 25° C.: $a = 40.5$ cu.cm./g.mole, $\mu = 0.788$ centipoises, $D = 1.09$ sq.cm./sec.
[2] Plate widths as follows: Series a, 2.74 inches; Series b, 2.756 inches; Series c, 2.744 inches; Series d, 3.003 inches.

all the data points weighted equally, since any systematic error associated with one of the systems, such as a diffusion constant, would otherwise influence the final correlation in proportion to the number of runs made.

Within limitations of experimental error in determination of the mass-transfer coefficients and physical data entering into the correlation, Equations (32) or (35) appear to give satisfactory agreement with the data, the more simple Equation (33) being adequate for systems of high Schmidt number.

Constants for the various individual systems and the range of property values covered are listed in Table 5. Due caution should be observed if the correlation is extended to systems of widely different physical properties, although the results are believed to be general for conditions of laminar flow within the boundary layer.

The close agreement between results for electrolysis and for solid dissolution is an encouraging indication of the general validity of the theory and method of correlation. It may also be concluded that within the range of dissolution rates covered herein, the assumption of interfacial equilibrium is not significantly in error for the organic acids involved. Thus it would appear that there is no appreciable resistance to mass transfer in these systems other than that resulting from hydrodynamic and diffusional considerations.

Acknowledgment
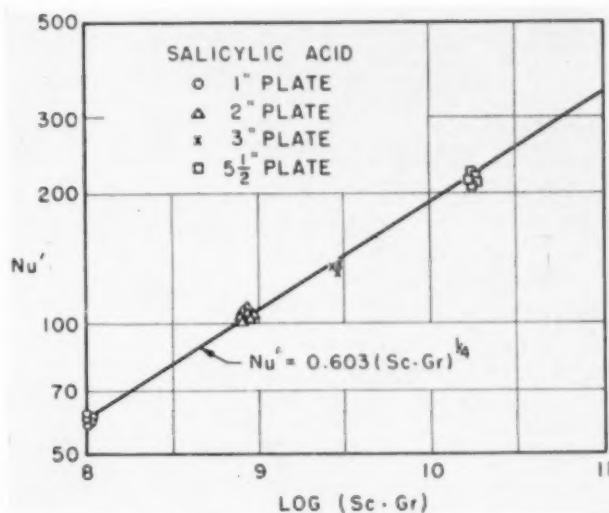
Fig. 12. Dissolution of salicylic acid.
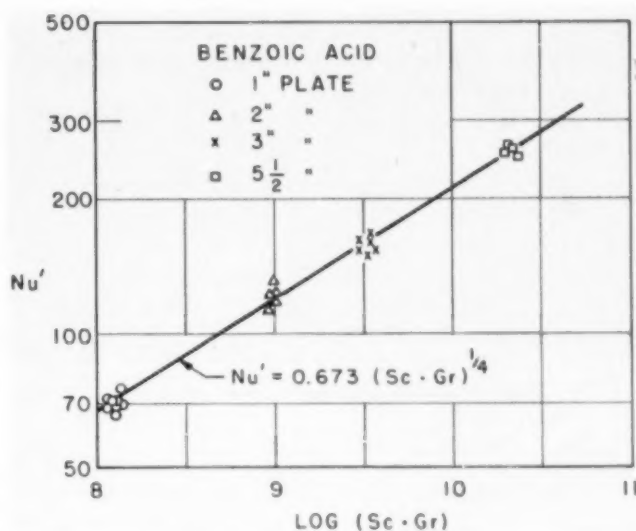
Fig. 13. Dissolution of benzoic acid.

Table 5.—Summary of Range of Experimental Variables and Results

Range of Experimental Variables and Results	AgClO₄ in HClO₄	Benzoic Acid	Salicylic Acid	CuSO₄ in H₂SO₄	CuSO₄ in H₂SO₄ (glycerol)
			System		
Plate height, in.	0.25–3.0	1–5.5	1–5.5	0.25–3.0	0.25–3.00
Concentration differences, $C_o - C_i$ g.mole/l.	0.09–1.17	0.024–0.027	0.015–0.017	0.011–0.79	0.37–0.57
Average density, g./cc.	1.09–1.19	0.997	0.997	1.09–1.14	1.18–1.20
Viscosity, g./(sec.)(cm.)	0.80–0.86	0.88–0.90	0.88–0.89	1.17–1.70	4.2–10.6
Diffusion coefficient, sq.cm./sec. $\times 10^6$	1.77–2.03	0.93–0.95	1.09–1.11	0.44–0.65	0.21–0.27
Mass-transfer coefficient cm./sec. $\times 10^3$	0.80–1.95	0.17–0.27	0.17–0.27	0.18–0.77	0.065–0.32
Nusselt number	39–577	67–263	58–226	42–563	74–481
Grashof number $\times 10^{-6}$	0.037–760	0.129–23.0	0.124–21.9	0.0068–235	0.0014–21.3
Schmidt number	406–446	937–965	796–821	1662–3370	13,300–83,000
Average constant in Equation (33)	0.657	0.673	0.603	0.673	0.711

Fig. 14. General correlation for free convection.

The figure shows a log-log plot of Nu' versus $LOG(Sc \cdot Gr)$ with the correlation:

$$Nu' = 0.66 (Sc \cdot Gr)^{1/4}$$

Legend:
- ○ SALICYLIC ACID
- □ BENZOIC ACID
- ▽ $AgClO_4 - HClO_4$
- △ $CuSO_4 - H_2SO_4$

Subscripts:

A, B, C, denoting various species

i denoting interfacial condition

o denoting condition in bulk solution

lm denoting log-mean average

x denoting local value at point x

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Notation

B = boundary layer thickness, cm.

c = concentration, g. ions or g. mole/cu. cm.

C = constant

D = diffusion coefficient, sq.cm./sec.

F = the Faraday, coulombs/g.-equivalent, also used to designate force

g = acceleration of gravity, cm./sq.sec.

Gr = Grashof number

I = current density, ma./sq.cm.

k_L = mass-transfer coefficient, cm./sec.

n = valence charge of an ion

N_c = rate of convection, g. ions or g. mole/(sq.cm.)(sec.)

N_d = rate of diffusion, g. ions or g. mole/sq.cm.(sec.)

N_D = rate of mass transfer by free convection

N_m = rate of migration

N_t = total rate of transfer

Nu' = Nusselt number for mass transfer,

$$\frac{k_L X_f x}{D}$$

Sc = Schmidt number,

$$\frac{\mu}{\rho D}$$

t = transference number

U = velocity in x direction, cm./sec.

V = velocity in y direction, cm./sec. or molal volume, cu.cm./g. mole

x = distance in the vertical direction, cm., or electrode height

X_f = film factor for mass transfer

y = distance in direction of mass transfer, cm.

a = specific densification coefficient

μ = viscosity, g./(cm.)(sec.)

ρ = fluid density, g./cu.cm.

ψ = defined by Equation (31)

ALUMINUM ALLOY REFERENCE SHEET

HARRY W. FRITTS — Aluminum Company of America, New Kensington, Pa.

WROUGHT ALLOY BD1S or 99.6 ALUMINUM

COMMERCIAL PRODUCTS: Sheet and plate—standard; tube, pipe, and extrusions—special.

APPLICATIONS AND REMARKS: Alloy BD1S, because of its high purity offers slightly better resistance to corrosion than other more common aluminum alloys. It is used extensively in the manufacture, handling, storage and shipment of hydrogen peroxide because it does not catalyze the decomposition of this chemical. Other applications are made in the brewery and dairy industries and for handling fuming nitric acids. The availability of aluminum alloys with superior mechanical properties limits the use of this alloy in the process

industries. This alloy is included in section 8 of the 1952 A.S.M.E. Boiler and Pressure Vessel Code.

ALUMINUM ALLOY

A.S.T.M. Designation: 996A

A.S.T.M. Specifications: B178, B274

Mechanical Properties, Typical:

	Temper Designation		
	—O	—H14	—H18
Tensile strength, lb./sq.in.	10,000	14,000	19,000
Yield strength, lb./sq.in.	4,000	13,000	18,000
Elongation—% in 2 in. (1/16 in. sheet)	45	12	6
Shearing strength, lb./sq.in.	7,000	9,000	11,000
Brinell hardness—500 kg load, 10 mm. ball	19	26	35

Physical Properties:

Modulus of elasticity, lb./sq.in.	9,800,000
Specific gravity	2.70
Weight—lb./cu.in.	0.098
Melting range, °F.	1196°-1214°
Thermal conductivity	
—B.t.u./(hr.)(sq.ft.)(°F./in.)	1568 (—O) 1539 (—H18)

Average coefficient of thermal expansion —in./°F. x 10⁻⁶

—76° — +68°		12.0
68° — 212°		13.0
68° — 392°		13.6
68° — 572°		14.2

COMPOSITION: 99.6% Al minimum.

FORMABILITY: This alloy is soft, ductile, and easily formed. It can be machined if necessary. Cuttings will be stringy and weak. Use high machine speeds and high rake angle.

HEAT-TREATMENT: BD1S is a nonheat-treatable wrought alloy. The strength is increased by cold working.

WELDABILITY: All the common methods can be used to weld alloy BD1S. Inert gas shielded arc welding is preferred where flux removal would be troublesome. Filler rods of similar composition should be used. Weld areas are not considered subject to selective attack, nor is stress relieving necessary.

CORROSION RESISTANCE

ACIDS
Acetic, all concs., r.t.*	E
Acetic, other than glacial, boiling	P
Acetic glacial, boiling *	E¹
Acetic anhydride, r.t.*	E
Acrylic, glacial, r.t.*	E
Benzoic, sat. soln. boiling *	E
Boric, 7% soln., 180° F.*	E
Butyric, all concs., r.t.*	E
Butyric anhydride, r.t.*	E
Carbolic (phenol), all concs., to 240° F.*	E
Carbonic, all concs., r.t.*	E
Chromic, below 10%, r.t.	G
Citric, 50%, to 200° F.*	G
Cresylic (Cresol), r.t.	E¹
Fatty, up to boiling *	E
Hydrochloric, all concs.	N
Hydrocyanic, all concs., r.t.*	E
Hydrofluoric anhydrous, 200° F.*	E
Hydrofluoric solutions	N
Lactic, anhydrous, r.t.*	E
Lactic, up to 10%, r.t.*	E
Maleic, 30%, r.t.	E
Maleic anhydride, molten *	E
Malic, to 50%, r.t.	E
Naphthenic, up to 180° F.*	E¹
Nitric, above 82%, to 120° F.*	E
Nitric, below 82%, r.t.	P
Nitric, red fuming, up to 120° F *	E¹
Oleic, up to boiling *	E
Oxalic, all concs., r.t.*	G
Oxalic, all concs., elevated temp.	P
Phosphoric, all concs.	N
Phthalic, molten	E
Phthalic anhydride, molten *	E
Propionic, all concs., r.t.*	E
Propionic, anhydride, r.t.*	E
Stearic, up to boiling *	E¹
Sulfuric, fuming	G
Sulfuric, other than fuming	N
Sulfurous, r.t.	F
Tannic, all concs., pure, r.t.	E
Tartaric, all concs., r.t.*	E

ALKALIES
Ammonium hydroxide, comm'l., r.t.*	E
Calcium hydroxide, all concs.	P
Potassium hydroxide, all concs.	N
Sodium hydroxide, all concs.	N

ALKALINE SALTS
Potassium carbonate, all concs.	P
Sodium bicarbonate, r.t.*	E
Sodium carbonate, all concs.	P
Sodium sulfide	P

NEUTRAL SALTS
Calcium chloride, all concs., to 200° F.	G*
Calcium sulfate, sat. soln., r.t.*	G*
Calcium sulfate, all concs., r.t.*	G
Magnesium chloride, all concs., r.t.	G*
Magnesium sulfate, to 50% soln.*	G
Potassium chloride, all concs., r.t.	G*⁰
Potassium nitrate, all concs., r.t.	E
Potassium sulfate, all concs., r.t.	E
Sodium chloride, all concs., r.t.*	G*⁰
Sodium sulfate, all concs., r.t.*	E
Sodium sulfate, all concs., r.t.*	E

ACID SALTS
Alum, paper makers, r.t.	E
Aluminum chloride, dry, 70° F.	G
Aluminum chloride, moist	P
Aluminum sulfate, r.t.*	E
Aluminum chloride, all concs., r.t.*	G*
Ammonium nitrate, all concs., to 285° F.*	E
Ammonium sulfate, all concs., r.t.*	E
Copper chloride, nitrate, sulfate.	P*
Ferric chloride, nitrate, sulfate	P*
Lead chloride, nitrate, sulfate	P*
Mercury salts	N*
Nickel chloride, nitrate, sulfate.	P*
Silver salts	P*
Stannous and stannic salts	P*
Zinc chloride	P*

GASES
Acetylene, dry *	E
Air, wet or dry, hot or cold *	E
Ammonia, dry *	E
Bromine	N
Carbon dioxide, wet or dry, hot or cold *	E
Chlorine, wet or elevated temps.	N
Freons *	E
Hydrogen sulfide, wet or dry, hot or cold *	E
Nitrogen, wet or dry, hot or cold *	E
Oxygen, wet or dry, hot or cold *	E
Sulfur, dioxide, dry	E
Sulfur, dioxide, wet	F

ORGANIC MATERIALS
Acetone, r.t.*	E
Alcohols, methyl, ethyl, etc., pure, r.t.*	E
Aniline, all concs., to 212° F.	G
Benzaldehyde, r.t.*	E
Benzene, to boiling *	E
Carbon disulfide, to boiling *	E
Carbon tetrachloride, dry, r.t.*	E
Chloroform, dry, r.t.	E
Ethyl acetate, pure, r.t.	E

(right column, top)
Formaldehyde *	G*
Furfural, r.t.*	E
Gasoline, to boiling *	E
Glycerine, to boiling *	E
Glycols, ethylene and propylene, r.t.*	E
Mercaptans, amyl, r.t.*	E
Methyl ethyl ketone *	E
Oils, crude, essential, refined vegetable *	E
Oils, sour crude (H₂S) *	E
Trichloroethylene, dry, r.t.*	E

PICKLING OPERATIONS
Acetic acid (Mag. Products)*	E*
Sulfuric plus dichromate	N
Sulfuric plus hydrochloric	N

FOOD INDUSTRY
Brines, inhibited *	E
Edible oils and fats *	E
Fatty acids *	E
Fruits and fruit juices *	G
Vegetables *	G
Milk products *	E
Beer *	E

PAPER MILL APPLICATIONS
Kraft liquor	N
Black liquor	N
Green liquor	N
White liquor	F*
Sulfite liquor	P
Chloride bleach solution	P
Chloride bleach vapors	G
Hydrogen peroxide (above 30%)*	E
Paper makers alum *	E
Humid and chemical atmospheres *	E

PHOTOGRAPHIC INDUSTRY
Humid atmospheres *	E
Cellulose acetates *	E
Acetic anhydride *	E
Developers	P
Silver nitrate	P*
Solutions containing SO₂	P

FERTILIZER INDUSTRY
Ammonia, anhydrous *	E
Ammoniated ammonium nitrates *	E
Urea *	E

* Aluminum alloys used commercially.

° Subject to pitting-type corrosion

¹ Must have trace of moisture present at boiling temperature.

² May be inhibited with sodium chromate.

RATINGS:

E—*Excellent resistance. 0.001 max. in./year of penetration. Corrosion so slight as to be harmless.*

G—*Good resistance. 0.001-0.012 in./year of penetration. Satisfactory service expected; at most a slight etch.*

F—*Fair resistance. 0.012-0.120 in. of penetration/year. Satisfactory service under specific conditions. Light to moderate attack.*

P—*Poor resistance. 0.120-0.420 in. of penetration/year. Satisfactory for temporary service only.*
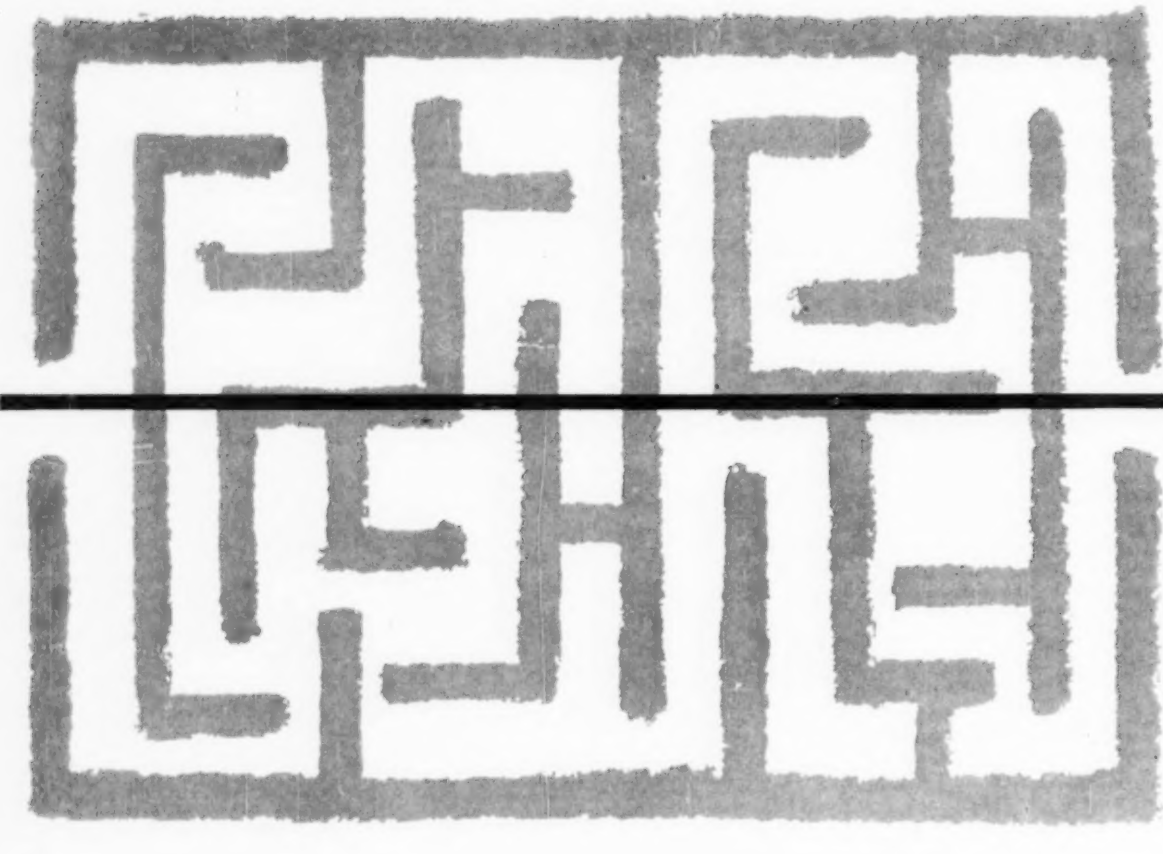
N—*Aluminum not recommended. Rate of attack high.*

r.t.—*Room temperature.*

No. 28

In any realistic discussion of creativity on the part of scientists, certain basic assumptions must be made; for example, that a scientist is capable of logical and reflective thinking, and further, that a research scientist is willing to work and *slave* and *follow through*. This latter step involves painstaking details and even drudgery, but it is a prerequisite for the fruition of creative ideas.

It is the author's conviction that creative abilities are not primarily a gift of the gods, but rather are the fruits of opportunity, stimulation, and growth. Much creative potential never emerges, a condition caused by faulty educational methods in early life and subsequently furthered by the demands of the work-a-day world, which is primarily concerned with the practical use of ability rather than the development of potential ability. Apposite to this point, H. G. Wells (3) once said:

England alone in the last three centuries must have produced scores of Newtons who never learned to read, hundreds of Darwins, Daltons, Bacons, and Huxleys, who died in stunted hovels, or never got a chance to prove their quality. All the world over there must have been myriads of potential first-class investigators, splendid artists, creative minds, who never caught a gleam of inspiration or opportunity for every one of that kind, who has left his mark upon the world.

The tragedy of this loss of creative power which has resulted from neglect is felt keenly, but even more keenly felt is the disappointment with those people who fail to use or release their creative power and special talents, especially when they find themselves in an environment which depends upon creative ability for its survival.

What Is Creativity?

In the usual sense of the word, creativity or creativeness means the bringing into being, the producing, the fashioning, the inventing, or the originating. Creative work or creative thinking ranges from a simple recombination of old ideas or known facts into new ways, to the pioneering and exploring for landmarks and direction in unchartered fields.

Creative thinking involves the following: (1) preparation—looking at all aspects of a problem; (2) incubation—assimilation of ideas; (3) illumination—happy ideas or a sudden insight, and (4) verification—testing the validity of the idea.

Creative thinking is closely akin to what psychologists formerly called creative imagination. A number of instances can be cited where a dream or a comatose condition was responsible for a piece of creative work, such as is claimed for Coleridge's "The Rime of the Ancient Mariner" or "Kubla Khan." It is well known that mathematical problems, research difficulties and many other problems are often solved by subconscious activity, a sudden flash of insight, or when no conscious or active effort is apparent. The best opinion seems to be that, at such times, inhibitions fall away so that insight has a better chance to emerge.

These facts should not lead to the conclusion that genius or brilliant work all comes by flashes or in our dreams. It has been said that Anatole France and Flaubert expressed their struggle with ideas as follows:

1. I write with difficulty . . . I have no imagination but I am not without patience . . . you become a good writer just as you become a good joiner: by planing down your sentences.

2. See the years I struggle to perfect just one novel, while you are pouring out a dozen! Why, I sit sometimes for hours at the table, without a word, just trying to chisel out one little phrase.

Edison, a great creative genius, has said:

Charles D. Flory

Rohrer, Hibler & Replogle, New York

Charles D. Flory, the author of the accompanying article, is a Ph.D. from the University of Chicago. He has had fifteen years' teaching experience in the field of psychology and for ten years served as a psychological consultant to management. For the past eight years Dr. Flory has been a partner in the firm of Rohrer, Hibler & Replogle in charge of the New York office. In this paper Dr. Flory explains how creativity can be stimulated.

DEVELOPING AND USING OUR CREATIVE ABILITIES

When it comes to problems of a mechanical nature, I want to tell you that all I have ever tackled and solved have been done by hard, logical thinking. I speak without exaggeration when I say that I have constructed three thousand different theories in connection with the electric light, yet in two cases only, did my experiments prove the truth of my theory.

One of Edison's associates, on the other hand, who had worked for more than a year to develop a wax for phonograph cylinders, reported "then the solution came like a flash of lightning—not the Edison way. . . ."

Though the literature offers little elucidation on the meaning of creative thinking, it abounds with evidence on the nature of reflective thinking.

It is generally agreed that reflective thinking involves: (1) a felt difficulty; (2) observation and fact-gathering; (3) constructing and testing hypotheses, and (4) drawing conclusions and generalizations.

Fletcher's analysis (1a), showing the differences between reflective and creative thinking, stresses the following:

1. Reflective thinking can be carried on at superficial levels—the juggling of facts, tables, and formulae; while creativity once started cannot be stopped by the clock; it has a dynamic quality.

2 Reflective thinking deals with the techniques of thought, but creativity deals with the content of thought.

3. Reflection can take place irrespective of mood, but creativity is inseparably tied to mood and sometimes even to place.

4. Reflection is focal and directed to a definite point, whereas creative effort is often marginal and vague.

5. Reflection can be directed voluntarily, but creativity is more spontaneous and automatic.

6. Reflection is often toilsome with the goal beyond the act, but real creativity is absorbing and interesting in itself.

7. Reflection is cognitive—thus one may argue on either side of a question, but creative thinking is effected by deep feelings, urges and attitudes.

8. Reflection can be scheduled and routinized, but creativity can be neither started nor stopped by a bell.

9. Reflective thinking is normative and conforming, and creativity requires freedom and is often unconventional.

10. Reflection deteriorates slowly by neglect; creativity is lost rapidly and easily destroyed by misuse or neglect.

In a similar vein, A. H. Maslow, in an article titled "Problem-Centering vs. Means-Centering in Science" (2) makes some observations which bear upon creativity. The creative scientist is primarily problem-centered, but the technician is usually means-centered. The latter is concerned with polish, apparatus, buildings, titles, and prestige symbols, and the former is concerned with meaningfulness, vitality, and the significance of problems in general—in short, with creativity.

Technicians tend to be apparatus men and methodologists, and creative workers are question-askers and problem-solvers. The first are concerned primarily with *how* a problem should be solved, but the latter want to know *what* problems should be solved. The technician becomes overconcerned with quantitative facts and the way in which they are expressed; the creative scientist is interested in results and valuable contributions. The man whose primary interest is methodology tends to fit problems into his techniques rather than find or invent techniques which will supply solutions to problems. Those who emphasize *means* foster the building of walls that divide science into discrete and separate territories; these people become engineers, chemists, physicists, psychologists or mathematicians. The creative man has little concern for the walls of a discipline or even for departments when such dimensions get in the way of problem solving. Scientists who are creative find more similarities among their fellow scientists than they find differences, thus a creative spirit finds other creative workers mutually collaborative, irrespective of their degrees, their titles, or their labels. Someone has pointed out on this angle that the degrees a man has accumulated indicate

only degrees of exposure rather than a guarantee of creativity.

Maslow aptly states that emphasis on techniques "encourages scientists to be safe rather than bold and daring. . . . It tends to make him [the scientist] into a settler rather than a pioneer. . . . The proper place for the scientist—once in a while at least—is in the midst of the unknown, the chaotic, the dimly seen, the unmanageable, the mysterious, the not-yet-well-phrased."

Impediments to Creativity

Since the thesis of this paper is that creativity can be developed, the fact must also be accepted that it is often blocked, stunted or even killed by the conditions surrounding the scientist or the things that happen to him. The conditions or situations most likely to work against high-level creativity can be summarized as follows:

1. Overregulation and overcontrol which result in setting up so many intellectual fences that the ground to be plowed yields a meager crop.

2. Setting time limits on creative results. The *what* and *how* can be planned. The *who* and *where* can be scheduled, but the *when* of a creative idea can by no stretch of the imagination be put into a time schedule (1). The only type of research in which the *when* can even approximately be scheduled is that type of applied research which has to do with development.

3. Criticism leveled against the man with a creative idea is like the withering blasts of a furnace on tender plants. Overcritical attitudes or a lack of sympathy for unconventional thinking will dry up the springs from which creative ideas flow.

4. Demanding logical inferences when creative thinking is needed will, in the long pull, stereotype productivity until it becomes sterile. Even to the creator himself, the initial stages of his thinking may seem to involve commerce with disorder. The faithful formalist has little chance of creating anything.

5. A failure to provide opportunities for creativity with a persistent lack of appreciation for creative ideas, or a failure to recognize creativity when it occurs will certainly pinch it off in the bud.

6. A failure on the part of the scientist himself to use facts as a springboard into the unknown and unchartered areas will make it increasingly difficult for him to come up with new ideas. Creativity is almost always a movement beyond the established.

7. Mistaking activity for creativity tends to reward motion rather than progress.

8. Assuming that any novel idea is a creative idea may lead to superficiality rather than penetration.

9. An idea which flows with such rapidity that it aborts before it matures, and thereby defeats its own purpose. There are some individuals who can lay eggs at a rapid rate but they lack the ability to hatch the eggs that have been laid. When the less inventive tasks involved in effecting an idea loom ahead, they rush to something else which is more stimulating because of its freshness.

10. Emotional states—person-to-person, person-to-place, person-to-groups, or person-to-controls —will certainly block ideas, since it is a well-known fact that thinking is inhibited rather than facilitated by feeling.

A study was made by Van Zelst and Kerr (4) of 467 scientists to determine their reaction to supervision vs. freedom in research. They found that the average scientist in this study is 35 years of age, a member of four societies, reads four to five technical journals, works 43 to 44 hours a week and 3 to 4 hours a day at home.

In this group 8 per cent work best for the incentive of industrial profits, 19 per cent for personal gain, and 73 per cent for the general good. Of the group, 26 per cent want no deadlines, 23 per cent prefer that supervisors set theirs, and 51 per cent prefer to set their own.

By way of summary, it was found that the men who produced most "had more academic degrees, read more journals, belonged to more societies, put less emphasis on equality among associates, liked to set their own deadlines for their projects and were motivated more by altruistic goals." The study also suggested that "maximum productivity was achieved with (a) 28 hours per week of regimented work and (b) 3.5 hours per day of related homework. While this finding does not advocate a 28-hour work week, certainly, no one will question the wisdom of keeping creative workers as free as possible of routine and rigid assignments."

Characteristics of Creative People

It is apparent from what has already been said that creativity is more a matter of people than of place, environment, organization or management. All or any of these conditions can assist or aid creativity, but they are no substitute for ability. What are some of the characteristics of creative people? The creative person is likely to be:

1. Flexible—knows when to abandon false leads.

2. Imaginative—venturesome, willing to go beyond the facts—to strike out on his own.

3. Inquisitive—looks, questions, and seeks.

4. Persistent—painstaking and untiring, as long as there is hope for a solution.

5. Pioneering—a frontier thinker who often has difficulty in communicating his thinking since he chases ideas which are often beyond the range of understanding even of his colleagues.

6. Sensitive—perceptive of cues and responsive to stimuli.

7. Unconventional—individualistic in that he not only tries new paths but also makes them.

Stimulating Creativity

Throughout this paper the necessity for stimulating creativity has been emphasized. Some ways or means in which creative thinking and productivity can be encouraged are as follows:

1. An environment of freedom—freedom in this sense means merely room to project and unfold ideas until they emerge as solutions to problems.

2. Sufficient security to reduce tension, but not so much security that one becomes complacent.

3. Reduction of routine, so that creativity is not killed. About 70 per cent of a research man's time is devoted to the informational aspect of his project, including search, report-writing, abstracting, indexing, and the like.

4. A fallow period either during the search for solutions or between projects which will foster and encourage incubation.

5. Adequate rewards for the work done —anticipation of success; solution to problems; recognition by colleagues and other scientists; prestige that comes from quality work; and financial returns.

6. Ability to work as often as possible on his own projects or problems which are keenly interesting to him.

Bush and Hattery (1) aptly, and by way of summary, have the following to say about creative research: "Research is not subject to command; rather, it grows spontaneously. Like all growth, it may languish and die . . . The outcome cannot be forced by dollars . . . it can only be encouraged . . . Rearrange the dynamic factors of the configuration and start over, and over, and over."

Creativity is within you; suppress it and it dies; express it again and again, and it takes shape, form, and life.

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NEW AMMONIA UNITS ON STREAM AND IN CONSTRUCTION
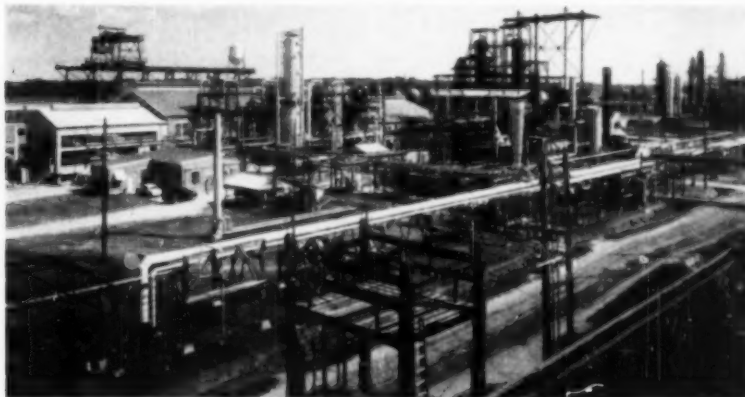
The $20,000,000 additions to Commercial Solvents Corp.'s ammonia and methanol production facilities were opened recently at Sterlington, La. More than 70,000 additional tons of nitrogen-bearing ammonia and 15,000,000 additional gallons of methanol a year will be produced, according to the company.

Using approximately 50,000,000 cu.ft. of natural gas a year, the ammonia produced in the new plant will be processed, company officials said, into 75,000 tons of ammonium nitrate fertilizer and 30,000 tons of nitrogen solutions, both for use in crop fertilization. Nitrogen will be produced in the form of anhydrous ammonia, solid nitrate, and solutions for mixed fertilizers. A new process for producing ammonium nitrate fertilizer, called the Stengel process, is being used, which eliminates conventional prilling towers, coolers, and driers.

A daily capacity of more than 300 tons has been announced by American Cyanamid Co. for the anhydrous ammonia plant that it is building near New Orleans, La. This is double the production capacity originally planned. The ammonia unit is shown above.

The Fortier plant, to be built at a cost of $50 million, will produce nitrogen chemicals from natural gas. Besides anhydrous ammonia, acetylene, hydrocyanic acid and such derivatives as acrylonitrile and ammonium sulfate will be manufactured. Although the larger part of the ammonia produced will be used for agricultural purposes in the region, the company said, a portion will be diverted to the manufacture of the other chemicals.

W. R. MARSHALL, JR., RECEIVES WALKER AWARD

The William H. Walker Award for 1953 was made to W. R. Marshall, Jr., "in recognition of his unique and distinguished record of publication in the fields of atomization of liquids and drying." Dr. Marshall, the eighteenth member to receive the award, is the fifth in an unbroken line of professors so honored.

Presentation of this and the other major awards of the Institute, announced last month, took place at the Awards Banquet held on Dec. 15 during the Annual Meeting in St. Louis. Olaf A. Hougen was chairman of the Awards Committee.

Dr. Marshall, who is associate dean of the college of engineering and professor of chemical engineering at the University of Wisconsin, received the award for his contributions to Chemical Engineering Progress during the three-year period 1950-1952. The papers were "Principles of Spray Drying" (with E. Seltzer), 1950; "Temperature Gradients in Gas Stream Flowing Through Fixed Granular Beds" (with C. A. Coberly), 1951; "Performance of Spinning Disk Atomizers" (with C. R. Adler), 1951; "Freeze Drying with Radiant Energy" (with W. H. Zamzow), 1952; "Evaporation from Drops" (with W. E. Ranz), 1952; and "Centrifugal Disk Atomization" (with S. J. Friedman and F. A. Gluckert), 1952.

A native of Canada, Dr. Marshall came to the United States in 1925. He received a B.S. in chemical engineering from the Armour Institute of Technology in 1938 and a Ph.D. from the University of Wisconsin in 1941. Beginning his career in industry, he was with Du Pont Co., where he engaged in research and development in connection with drying and related problems, from 1941 to 1947, when he left to enter the academic field. As associate professor

The 170-ft. stack in the National Petro-Chemicals Corporation ethylene plant is the tallest structure in the new $50 million complex at Tuscola, Ill. Temperatures exceed 1,400° F. in these ethane-cracking furnaces.

Petrochemical Plant Opened at Tuscola

In the middle of America's corn belt last month, the largest unit in the U. S. devoted solely to the manufacture of petrochemicals was dedicated by the National Petro-Chemicals Corp. At Tuscola, Ill., about 150 miles south of Chicago, the new corporation (owned 60% by National Distillers Products Corp., which manages and operates it, and 40% by Panhandle Eastern Pipeline Co.) officially opened its doors for inspection. What was on exhibit was a technologist's dream. Out of natural gas the company each year will turn 130,000,000 gal. of propane, 30,000,000 gal. of butane, 6,000,000 gal. of gasoline, 42,000,000 gal. of ethyl alcohol, 3,500,000 gal. of ethyl ether, and 50,000,000 lb. of ethyl chloride, the largest production from any one plant making these items.

Tied in with the present petrochemical unit is a U. S. Industrial Chemicals Division sulfuric acid plant and a compressor station on the Panhandle Eastern pipe line, which is adjacent to the petro plant.

And growth has not stopped; the management is currently planning a polyethylene unit, for which foundations have been dug, and an ammonia plant. The ammonia plant will cost $7,000,000 and will manufacture 50,000 tons of ammonia, part of which will be converted into nitric acid and ammonia nitrate. The polyethylene plant, to be in operation in 1955, is expected to produce 55,000,000 lb. of polyethylene a year. The Illinois Farm Supply Co. is considering a $3,000,000 installation near the plant site to produce nitrogen fertilizer from the ammonia and ammonia nitrate made at Petro.

Petro New to the Field

The giant Petro plant now operating in the heart of Illinois is new to the chemical field and just as new to the parent company. That the venture represents a deliberate and carefully planned expansion into the chemical field by a company seeking to diversify is manifested by the report that the president of National Distillers, John Bierwirth, moved into the top company spot only after obtaining a promise that National would continue a diversification into the chemical field, begun by its previous president, Seaton Porter. National Distillers had been a conservative whiskey house with few tangible outside interests when it embarked on its first chemical project, a $12,000,000 metallic-sodium plant, at Ashtabula, Ohio. This first expansion was done with the assistance of DuPont, which engineered and advised National on the operation of the sodium plant. National Petro was next formed by Bierwirth, and when it was in the engineering stage, National Distillers ventured further into the chemical field, first buying into and then merging with

U. S. Industrial Chemicals, Inc. It also bought a 20% interest in Intermountain Chemical Corp. (which mines natural soda ash); and then bought Algonquin Chemical Co., producers of chlorine, caustic soda, and sulfuric acid.

The idea for National Petro began when the then director of research and development for National Distillers, Robert E. Hulse, now vice-president of National Distillers and National Petro, approached the company directors with a plan to expand into petrochemicals. Dr. Hulse, a veteran of the DuPont organization, struck on petrochemicals as having a bright future. Two events forecast the success of the project: first the formation of the National Petro-Chemicals Corp. with Panhandle Eastern, and second the hiring of Arnold Belchetz, a consultant with many years' experience at Shell, Kellogg, and Stauffer, behind him. Belchetz was responsible for most of the economic planning and engineering details.

Of the four sites considered (one of them being on the Mississippi River, and another on the Illinois River, to enable inexpensive shipment of chemicals) Belchetz and National Petro-Chemicals finally settled on Tuscola as the most logical. The logic is immediately apparent from a pipe-line map. Tuscola sits astride a 1,200-mile pipe line which comes from the Hugoton and Panhandle fields in Texas as well as the pipe line of the Trunkline Gas Co. which taps the Louisiana Gulf Coast fields. The original economic balance as determined by Belchetz indicated that hydrocarbons could be safely extracted from 400,000,000 cu.ft. a day of Panhandle gas, which contains 12% nitrogen but nevertheless has a B.t.u. content of 1,000/cu.ft., and the stripped gas then mixed with Trunkline gas coming from the Gulf Coast, which has a B.t.u. content of 1,050/cu.ft., so that a minimum B.t.u. content of 975/cu.ft. could be maintained for industrial sales. It is from the extracted hydrocarbons, such as ethane, propane, and butane, that Petro predicates its present position and future sales. However, resources need not worry the management, for the proven reserves of the Hugoton and other fields of Panhandle ownership are measured in trillions of cubic feet.

Materials Flow

The plant units now in existence at Tuscola are an extraction plant, where the gases are processed before entering the compressor station, and a fractionation plant, where propane, isobutane,

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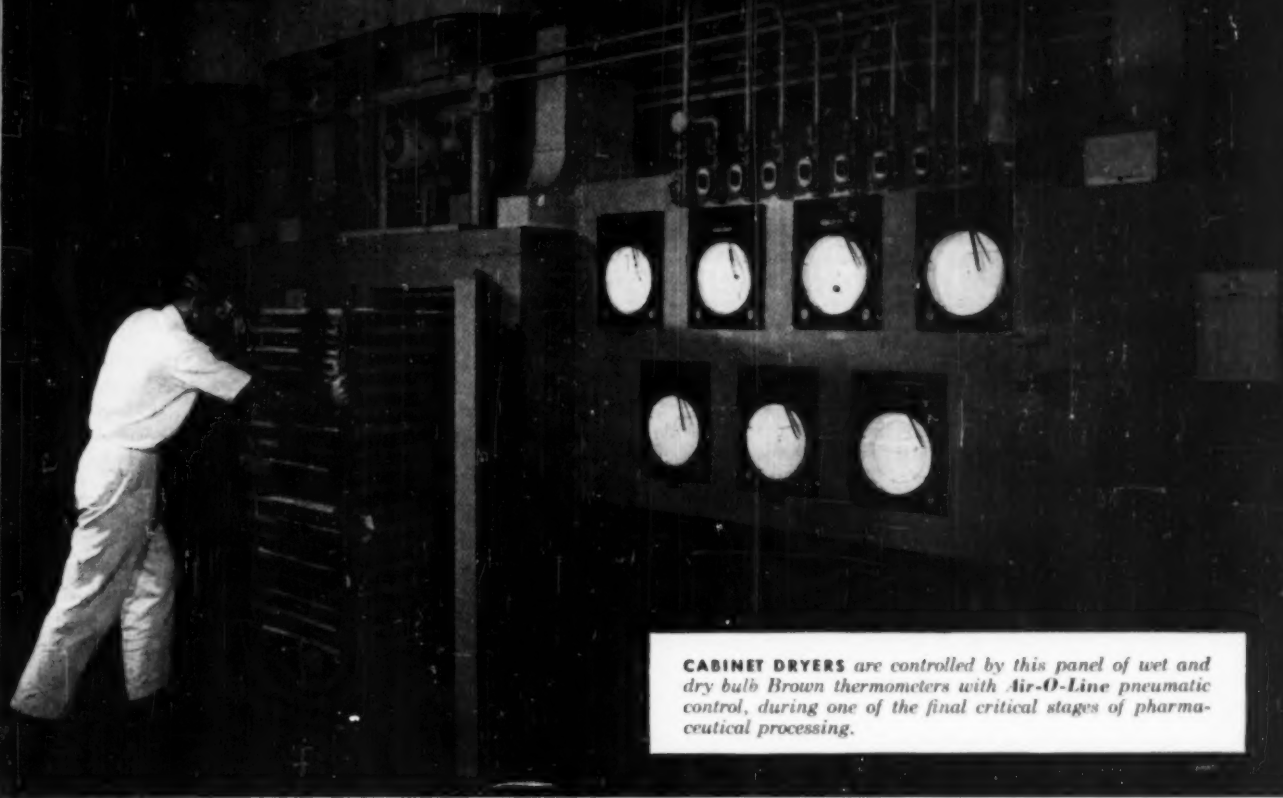
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n-butane, and natural gasoline, as well as ethane, are separated. The ethane goes to the ethylene plant, and the four other hydrocarbons are stored for tank-car and truck delivery to markets. The ethane passes through the ethylene plant, a fraction going to the ethyl chloride plant, another to the alcohol plant. A small amount of hydrogen from the ethylene plant goes to the ethyl chloride unit and the balance will go to the ammonia plant when it is completed. Alcohol and ether from the alcohol plant and ethyl chloride from the ethyl chloride plant go to tank-car loadings. The U. S. I. plant at Huntsville, Ala., formerly Algonquin, supplies the chlorine used in the ethyl chloride unit for making hydrochloric acid. Sulfuric acid is processed in the U. S. I. sulfuric acid plant, which receives 77 and 92% sulfuric acid from the alcohol unit and delivers 98% sulfuric acid in return.

Sales Return

The production of these huge amounts of chemicals would normally be a marketing problem of some proportion, but Petro officials had solved most of it long before the engineering of the plant was completed. Practically all of the L.P.G. is being purchased by Phillips, which created a market in Chicago when it convinced transportation companies there that they ought to convert some of their buses to propane use, and a large market for propane also exists in the northeastern states. Tuscola has the further advantage of being closer to the large northeastern market than any other source of propane. A large quantity of the ethyl alcohol is being sold to DuPont; the remainder is being purchased by Commercial Solvents and U. S. Industrial Chemicals. Ethyl chloride is being absorbed by DuPont and the ether by Koppers Co.

Processing Details

Natural gas is delivered to the extraction plant, which can handle normally 400 million cu.ft. of natural gas a day and a peak of 425 million cu.ft. From this stream, 10 million standard cubic feet of ethane (or approximately 40% of the ethane content) is extracted daily for the production of ethylene. In addition, essentially all the propane, isobutane, n-butane, and natural gasoline are removed from the natural gas stream.

The natural gas is first dehydrated to a −40° F. dew point to prevent freezing in the low-temperature process equipment. Approxi-

mately 7 lb. of water is removed from each million cubic foot of gas in Sovabead and Florite dehydrators, each of which contains a 9½-ft. bed of Sovabead packed between two 3-ft. beds of Florite. Operation is for 12 hr. followed by a 3-hr. regeneration and a 3-hr. cooling period.

The dehydrated gas is cooled by exchange with light-oil-absorber outlet gas and with propane refrigeration to a temperature of −20° F. before entering the light-oil absorbers. A −20° F. hexane cut is used as the absorbing medium at a rate of about 1,700 gal./min. Before entering two light-oil absorbers operating in parallel, the lean absorption oil as well as the gas stream splits. The heat of absorption is removed by two sets of intercoolers, chilled by propane refrigeration, thus obtaining an average operating temperature of the absorbers of about −10° F. Gas leaving the light-oil absorbers enters three heavy-oil absorbers operating in parallel, where the light oil present in the gas is recovered by absorption at a pressure of 480 lb./sq.in. gauge and a temperature of 60° F. The heavy absorption oil is charged to each absorber at a rate of about 180 gal./min., and a temperature of 50° F. The stripped gas now goes to the compressor station, where it enters the suction of the compressors. It is here that the blending of the several gas streams takes place, and the blending process caused no little cudgeling of engineering brains. Panhandle's problem, which they solved, was no mere precompression mixing, but the careful adjustment of the striped gas from Petro at 450 lb./sq.in. with the higher pressure lines from Texas and the Gulf. Petro, incidentally, is on a "hot-shot" line—meaning direct from Liberal, Kan., without any intervening sales from the line.

Rich oil leaving the heavy-oil absorbers is charged to the heavy-oil still, where the light and heavy oils are separated. Heat is supplied by a direct-fired reboiler with a duty of 50,000,000 B.t.u./hr. Rich oil from the light-oil absorber is charged to a demethanizer operating at about 405 lb./sq.in. gauge, where the absorbed methane is removed from the rich light oil. The methane is passed through a reabsorber, for marginal recovery of ethane, and then through a preabsorber, for presaturation of light lean oil with methane, prior to the return of the methane to the stripped-gas stream.

The rich oil from the demethanizer is then charged to two light-oil stills operating in parallel, where the extracted L.P.G. is separated from the light oil, condensed by water cooling, and sent to the fractionation unit for separation. Each light-oil still utilizes a direct-fired reboiler with a duty of 31,000,000 B.t.u./hr.

Propane refrigeration is supplied by three 4,000-hp. steam-turbine-driven centrifugal compressors, one of which is a spare unit. Propane at various saturation temperatures and pressures is vaporized into five separate stages of the compressor to provide refrigeration at −30°, −11°, 27°, 48°, and 70° F.

The L.P.G. stream from the extraction unit, consisting primarily of ethane and propane with lesser amounts of iso- and n-butane and natural

gasoline, is charged to a four-tower fractionation unit.

A 95% pure ethane stream is removed from the L.P.G. in a 26-tray deethanizer operating at 485 lb./sq.in. gauge. Part of the overhead is condensed by propane refrigeration for reflux purposes, and the remainder is sent to the ethylene plant as a vapor. The bottoms from the deethanizer are pressured to a 40-tray depropanizer operating at 205 lb./sq.in. gauge. The propane, 96% pure, goes to storage. The bottoms from the depropanizer are pressured into the debutanizer, where the iso- and n-butane are separated from the natural gasoline. The natural gasoline from the debutanizer is sent to storage and the butane fraction to the 70-tray deisobutanizer, consisting of two 35-tray towers in series, where the isobutane with a minimum purity of 95% is separated from the n-butane.

The daily production and storage capacities for the products are as follows:

Product	Production
Ethane	10,000,000 cu.ft./day
Propane	350,000-400,000 gal./day
Isobutane	30,000 gal./day
n-Butane	55,000 gal./day
Gasoline	10,000-19,000 gal./day

Ethylene Unit

Ethane from the fractionation plant is received at the ethylene plant for cracking and ethylene recovery. The ethane is first scrubbed with caustic to remove minor quantities of sulfur compounds which might be present, and then converted to ethylene at elevated temperatures in a bank of eight furnaces. The outlet pressure from the reaction zone is 25 lb./sq.in. gauge the residence time being very short.

The furnace or heater effluent, containing approximately 30% ethylene, is quenched by a water spray and further cooled by heat exchange with circulatory water. A waste-heat steam boiler has been built into the convection section of the furnace for recovery of heat from the flue gases. The cooled quench spray carries with it a large proportion of the tars, heavy polymers, and coke which may be formed. These materials are removed from the water in a surge drum prior to the reuse of the water.

Hydrocarbons from the quench drums are stripped of most compounds heavier than pentane in a light-oil absorption tower. The rich oil is steam stripped for reuse. The scrubbed gases from the absorber are compressed stepwise with cooling between each pressure stage.

Final utilization of the ethylene from this plant prohibits the presence of more than minor traces of acetylene in the end product. Therefore, practically all acetylene is converted to ethylene by

TWELVE MONTHS OF

NATIONAL CARBON'S GREATEST YEAR OF PRODUCT DEVELOPMENT BOOSTS THE BUYING POWER OF *YOUR* EQUIPMENT DOLLAR

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- *Design* know-how and facilities pre-eminent in the field
- *Application* experience of long standing

HERE'S WHAT CAME OUT OF THE PROGRAM:

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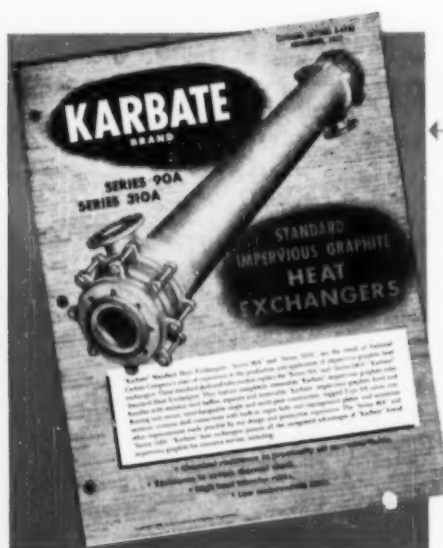
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PETROCHEMICAL

catalytic hydrogenation, which is carried out at moderate pressure and at slightly elevated temperatures.

The wet gas from the converters is further compressed with interstage cooling and subsequent water knock-out and dried with trays of activated aluminum oxide. Regeneration of the drier trays is carried out with heated gas from the cracking heaters.

The exit gas from the driers is cooled by propane refrigeration and charged into a refrigerated absorption tower for the separation of methane and hydrogen from the mixture of ethylene, unconverted ethane and higher molecular-weight hydrocarbons.

The absorber overhead of hydrogen (8,000,000 cu.ft./day) and methane contains small amounts of higher molecular-weight compounds, including some lean oil. A portion of the absorbed overhead is refrigerated to extremely low temperatures, until all hydrocarbons have been condensed leaving an essentially pure hydrogen. The hydrogen obtained in this methane is sent to the ethyl chloride plant for combustion with chlorine. (However, in October, 1954, the balance of the hydrogen stream will be purified and used for ammonia production.) The condensed light oil is returned to the absorber. The other condensed hydrocarbons, consisting mostly of methanes, enter the plant fuel system. Cooling the main portion of the overhead gas by expanding it through a turbogenerator, restores a portion of the energy of compression. After the expansion, most of the light oil is recovered as condensate. The remaining gas is utilized as fuel in the cracking furnaces.

When the ethane and ethylene are removed from the rich absorber oil in a deethanizer, a lean oil remains, which is contaminated with some higher olefins. A small percentage of the lean oil is rerun in a still column; the purified light oil is returned to the lean-oil reservoir.

The final tower in the ethylene plant fractionates the ethylene from the ethane present in the deethanizer overhead. Reflux is obtained by refrigeration and compression. The overhead product consists of an ethylene with a minimum purity of 95%.

Propane refrigeration is used throughout the entire unit, and two temperature levels are maintained, one at −15°F. and the other at 40° F. The refrigeration system uses two 4,400-hp. centrifugal compressors.

Ethyl Alcohol Plant

Ethyl alcohol is produced from ethylene by the sulfuric acid process. Ethylene is absorbed in strong sulfuric acid to form ethyl hydrogen sulfate and diethyl sulfate; the ethyl sulfates are hydrolyzed with water to form ethyl alcohol, and by-product diethyl ether, which are stripped from the acid. The acid is reconcentrated under vacuum and fortified for reuse in the process. The crude alcohol is refined by distillation to produce the final products of 190-proof ethyl alcohol and diethyl ether.

Approximately 7,700,000 cu.ft. a day of ethylene is supplied to the ethanol synthesis unit by the ethylene plant. This ethylene is reacted with strong sulfuric acid in two liquid-full, absorption towers, the absorption being carried out at elevated temperatures and pressures in order to complete the reaction in a reasonable reactor volume. The diluent gases in the feed, along with a small stream of unabsorbed ethylene, are vented from the absorbers and returned to the ethylene plant. The ethylene-sulfuric acid "absorbate" is discharged from the absorbers and sent to intermediate storage.

The hydrolysis step, carried out in a corrosion-resistant reactor, forms ethyl alcohol and diethyl ether. In a conventional-type distillation column, open steam is used to strip ethyl alcohol and ether from the weak sulfuric acid that was released by the hydrolysis of ethyl sulfates. Crude alcohol is neutralized with caustic and sent to storage, and spent acid from the stripper bottoms is pumped to storage before feeding to the acid concentrator.

The crude alcohol is refined in a series of distillation columns, first to remove ethyl ether, second to remove impurities boiling in the same range as alcohol, and third to refine the alcohol. Extractive distillation is used to remove impurities which are stripped from a dilute solution of alcohol under conditions where the relative volatilities are reversed. A batch still is available for occasional recovery of ether of special grades and also for recovery of alcohol and other components of the impurity stream.

The heat requirements of this purification system, with its large quantities of dilution water to be removed by distillation, were of prime importance in the design. To conserve heat, the columns employ a vapor-reuse system, open steam being supplied to the bottom of the rectifier and the overhead vapors used to supply heat to the reboilers of the ether and extractive-distillation columns. Reboiler condensate is then returned to the rectifier reflux drum. In

order to obtain a satisfactory temperature difference in the reboilers, the rectifier is operated under pressure.

The acid concentrators are conventional Simonson-Mantius vacuum units which raise the concentration of the weak acid to 92 wt.% sulfuric acid. There are six concentrations, operating at 4.0 and 0.4 in.Hg and using 65, 150, and 300 lb./sq.in. gauge steam in bayonet heaters. The concentrated acid is pumped to the sulfuric acid plant ($2 million cost, 140,000 tons/year) where it is fortified to full strength and returned to the alcohol unit. A portion of the acid is also removed from the concentrators at 77% acid strength for external sale, mostly for production of superphosphate.

Ethyl Chloride

In addition to supplying 7,700,000 cu.ft./day of ethylene for the ethanol-synthesis plant, the ethylene plant supplies approximately 1,000,000 cu.ft./day of ethylene and 500,000 cu.ft./day of by-product hydrogen for the ethyl chloride plant.

Chlorine is the other basic ingredient used in the plant. It is shipped in by tank car at the rate of a car a day, and storage facilities provide inventory for approximately a week's operation. The plant includes a unit for burning chlorine with by-product hydrogen from the ethylene plant, in Karbate furnaces. The products are recovered by absorption in muriatic acid, and the hydrogen chloride is stripped off prior to compression for the synthesis operation.

The ethyl chloride process combines hydrogen chloride and ethylene gases directly to produce ethyl chloride; approximately 50,000,000 lb. a year will be produced. Rectifying columns are used to produce pure ethyl chloride.

Water a Problem

The Kaskaskia River, which flows adjacent to the plant, is the source of water. In order to provide for period of low flow, a 100,000,000-gal. reservoir was built to provide surge and storage capacity. In addition, two wells capable of supplying 7,000,000 gal. of water daily were drilled 24 miles upstream of the plant so that when the normal flow in the Kaskaskia River falls to a low level, water may be pumped into the channel to supply the plant demands.

The extraction plant and site facilities, roads, boiler-house, etc., were constructed by J. F. Pritchard and Co.; the Lummus Co. was contractor for the ethylene plant; Vulcan Copper and Supply built the alcohol unit, and the ethyl chloride plant was constructed by Foster Wheeler.
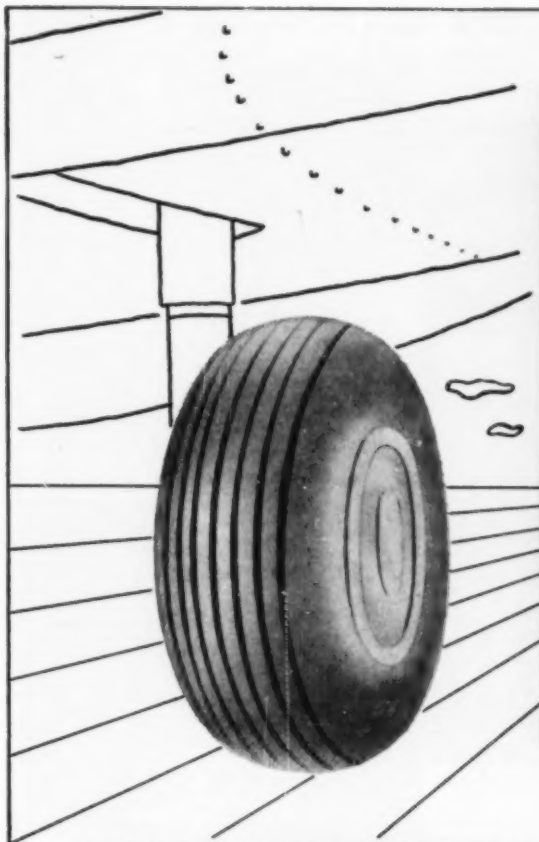
FORTUNATE ACCIDENT

In 1839 rubber wasn't much use. It melted and oozed in hot weather. In cold it stiffened and cracked. To remedy these failings, Charles Goodyear worked ardently but unsuccessfully. Yet he kept on. And the final solution of the problem came by accident when onto a hot stove Goodyear spilled a mixture of latex and Sulphur. This was the birth of vulcanization.

In the years since then, Sulphur has contributed further to rubber's versatility. By varying the proportion of Sulphur in the vulcanization mix, the properties of the rubber are changed — ranging from the battery case's rigidity to the rubber band's flexibility. And when supplies of natural rubber were cut off by war, Sulphur in various forms was found to be a most important element also in the production of synthetic rubbers.

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NEWS

TWO NEW TECHNICAL SERVICES IN 1954

Two new services to cover technical meetings and publications were announced last month. The American Petroleum Institute, Division of Refining, will inaugurate a new technical abstract service in January, and the Southwest Research Institute plans to publish a monthly calendar of technical meetings in the region, the first issue also to appear in January.

The A.P.I. bulletin, which will appear weekly, will cover 100 petroleum and chemical publications. Subscriptions may be obtained by writing to Louis C. Stork, Editor, Technical Abstract Service, American Petroleum Institute, 50 West 50 Street, New York 20. The price is $3,000 annually for five copies each week.

The monthly technical calendar of the Southwest Research Institute will be sent free to about 25,000 engineers and scientists in the region, which includes Louisiana, Oklahoma, Arkansas, New Mexico, Arizona, and Texas. Its purpose is to "assist in disseminating newly discovered scientific knowledge principally by listing meetings of technical groups in the six-state region."

SUPER-PRESSURES UNIT
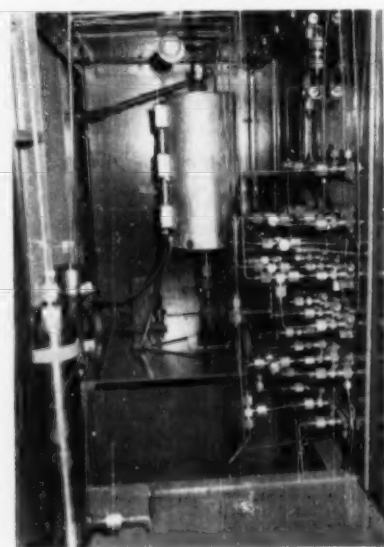
The newly dedicated super-pressures unit of the Ipatieff Catalytic and High Pressure Laboratories at Northwestern University, Evanston, Ill., promotes research on the application of super pressures to catalytic reactions of organic compounds. Above is the piping that connects the controls, installed for safety outside a ⅜-in. steel armor plate, with the unit. Reactions will be effected in flow-type high-pressure equipment at 25,000 lb./sq.in. and 1,000° F.

B.L.S. RESEARCH REPORT STUDIES ENGINEERS

An average of one and a half supporting workers was employed for each research engineer or scientist in 1951, according to a nationwide survey of industrial research and development recently issued in final form by the Research and Development Board of the Department of Defense and the Bureau of Labor Statistics.

In the 1,735 companies reporting supporting personnel (all with research programs), 143,000 supporting workers (draftsmen, laboratory assistants, other technicians, skilled craftsmen, and administrative, clerical, and maintenance personnel) and 95,700 professional research people were employed as of January, 1952. Of these, nearly 55% of the supporting personnel in the industries considered (food; textiles; paper; chemicals; petroleum refining; rubber; stone, clay, and glass; primary metal; fabricated metal; machinery; electrical machinery; transportation; and professional and scientific instruments, including photographic equipment) were employed in three industries, namely electrical machinery, aircraft, and chemicals; however the ratio of supporting workers to professional research personnel varied greatly: 2.0 for electrical machinery, 1.5 for aircraft, and 0.9 for chemicals. The greatest ratio of supporting to professional workers (5.2) in fact was not in the three leading industries but in motor vehicles.

Company Size

Even more pronounced than the distribution by industry, the report continued, was the concentration of supporting workers in the largest firms: 24% of supporting workers and 14% of research engineers and scientists being employed by the seven companies with more than 100,000 employees. For firms with over 5,000 workers the ratio of supporting to research personnel rose from 1.5 to 1.6. "In general," the report explained, "firms with large staffs have apparently found it feasible to have greater specialization of personnel than is practicable in smaller organizations. The relatively low support ratios of the small companies probably also reflect the fact that such firms often contract out much of their subprofessional work to drafting firms and machine shops, since their volume of work does not warrant the maintenance of a staff to perform these service functions."

Professional Research Personnel

Coincidentally, the same average ratio, 1.5, of supporting to research personnel held for the proportion of re-search engineers to total employees. In the chemical industry, however, the ratio was 3.0, 1.3 lower than the highest ratio, that for aircraft firms. Of the professional research engineers and scientists, approximately 40% worked for the forty-four largest companies, each of which had at least 25,000 employees; these companies represented only 2% of all the organizations (1,953) in the study. Two thirds of the professional researchers were with the 222 companies (11% of the total) with 5,000 or more employees, and only 4% worked for the 642 companies (33% of the total) with fewer than 100 employees.

Research Costs

The three fields leading in employment of research personnel (electrical machinery, aircraft, and chemicals) also had the highest total research costs, accounting for 54% of the 1951 costs reported. However the field with the lowest cost per research engineer or scientist ($16,500) was the chemicals industry. The average cost per professional researcher in all industries was $21,900. Further influence of the employment of supporting workers is shown in the research costs. Forty-four per cent of this cost was borne by eighteen companies with 1,000 or more research engineers and scientists, or 37% of the total professional employment. The smaller firms, with a total professional staff of less than 125, on the other hand, carried 21% of the research costs but employed 29% of the professional personnel. The greater supporting-personnel ratios in the larger firms added to research costs, the report explained.

Detailed information on research and development in industry is supplied in Bulletin 1148 of the Bureau of Labor Statistics, which may be obtained from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

OREGON STATE GETS NEW CHEM. ENG. BUILDING

A new chemical engineering building is being designed for Oregon State College, according to an announcement by J. S. Walton, Head of the Department of Chemical Engineering. Planned for occupancy by September, 1955, the building will house the various unit operations equipment and control laboratories and will provide space for research in such fields as wood, fuel, plastics, metallurgy, and electrochemical technology. Besides undergraduate research space, there will be several private research rooms for graduate students.

NOW!

SYMPOSIUM ON COMBUSTION FOR 1954

The Fifth International Symposium on Combustion will be held at the University of Pittsburgh on Aug. 30 through Sept. 3, 1954, under the auspices of the Standard Committee on Combustion Symposia.

The Fourth Symposium, held at the Massachusetts Institute of Technology in 1952, considered the physical aspects of combustion; the Fifth Symposium will emphasize the chemical aspects. An agenda follows:

1. Kinetics of combustion processes. Includes theory and experiments: preflame and flame kinetics; kinetics and mechanism of important oxidation reactions; kinetics of fast reactions; application of the spectroscopic method to chemical kinetics; new instrumentation in combustion kinetic research; application of kinetics to engine and other processes. There will be at least two invited papers in this field, one of which will probably be on the growth and decay of carbon in luminous flames. Otherwise a general invitation is extended for original contributions in this area.

2. Unsolved combustion problems in engines, including Otto, Diesel, rocket, ram-jet, pulse-jet, turbo-jet, gas turbine, etc. This section will be covered by a series of invited papers by experts on the various engines.

3. Several additional invited papers on the following subjects: scale effects (models) in combustion, space requirements for combustion, structure of combustion waves, theory of combustion (flammability and detonation).

4. Two round-table discussions to be announced later.

The committee requests that authors planning to contribute papers notify The Combustion Symposium Committee, attention of Dr. Bernard Lewis, U. S. Bureau of Mines, 4800 Forbes St., Pittsburgh 13, Pa., of their intention as soon as possible, whether or not an exact title is available. Abstracts of between 500 and 1,000 words are requested in triplicate not later than March 1, 1954.

PERKIN MEDAL GOES TO EDUCATOR

The Perkin Medal has been awarded for 1954 to Roger Adams, head of the department of chemistry and chemical engineering at the University of Illinois, it was announced recently by the American Section of the Society of Chemical Industry, which makes the award. Awarded for outstanding achievement in applied chemistry, the medal was established in 1906 and was first awarded to Sir William Henry Perkin, developer of the first synthetic dye.

HEAVY-INDUSTRY FABRICATION PLANT OPENED BY FOSTER WHEELER

Operation has begun at the new $5 million fabrication plant erected by Foster Wheeler Corp. at Mountaintop, Pa., for the fabrication of chemical plants, oil refineries, steam generating units, etc., according to a recent announcement, but full operation will not be underway until the first of the year. Among the major tools at the new installation are an 8,000-ton hydraulic beam press reported to be capable of bending plate 8 in. thick and a 2,000,000-volt Van de Graaff x-ray generator that will penetrate 12-in. steel.

Among Dr. Adams' achievements in applied chemistry are discovery of the platinum oxide catalyst, researches in stereochemistry, applications of new reagents to problems of organic chemistry, and contributions directly to the development of the American chemical industry as a consultant and top administrator. Besides over 350 scientific articles, Dr. Adams has written a textbook on organic chemistry, has been associate editor of the Journal of the American Chemical Society, and has been editor-in-chief of Organic Reactions. A graduate of Harvard University, from which he also has a Ph.D., Dr. Adams has received numerous honorary degrees and fellowships. He holds the William H. Nichols medal, Willard Gibbs medal, Priestley medal, Medal for Merit, and others.

Members of the Jury of Award of the Perkin Medal are officers of the American Section, Society of Chemical Industry, and representatives of A.I.Ch.E., A.C.S., Electrochemical Society, and the American Section of the Societe de Chimie Industrielle. Chairman of the jury was Harry B. McClure, executive vice-president of Carbide & Carbon Chemicals Corp. On Jan. 15, 1954, the forty-eighth impression of the Perkin Medal will be presented to Dr. Adams at a meeting of the American Section of the Society of Chemical Industry at the Waldorf-Astoria Hotel, New York.

WALKER AWARD

of chemical engineering at the University of Wisconsin, Dr. Marshall taught graduate courses, conducted research, and directed graduate students.

In July, 1953, he assumed his present titles and was also made associate director of the Engineering Experiment Station at Wisconsin.

In his work on drying, atomization, and heat transfer, Dr. Marshall has published over thirty papers. He is also coauthor of the Drying Section of Perry's "Chemical Engineers' Handbook" and of a text, "The Application of Differential Equations to Chemical Engineering Problems." His present work includes completion of a book on the principles of drying and of the monograph "Spray Drying and Atomization," much of the material from which was presented in 1952 as the fourth Institute Lecture, at the Cleveland meeting. This work will be published in the Chemical Engineering Progress Monograph Series sometime next year.

Currently chairman of the A.I.Ch.E. Committee on Equipment Testing Procedure, W. R. Marshall is also a member of the American Society of University Professors, American Society of Engineering Education, and American Chemical Society.

for your information

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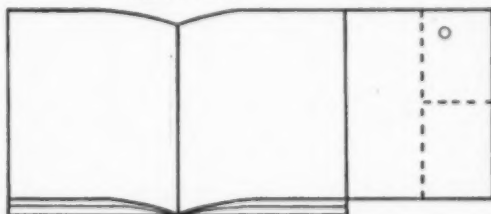
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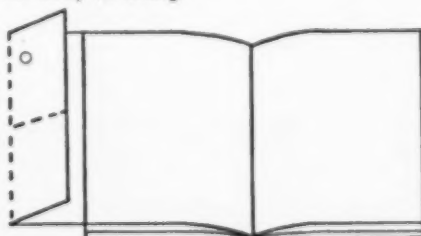
PRODUCTS

IFC Dryers
Custom-designed and tested dryers.
Louisville Drying Machinery Unit, General American Transportation Corp.

3R Instrumentation for Variables
For the measurement and control of variables.
Fischer & Porter Co.

4L Dryers
Metal-to-metal seals, choice of materials, anti-friction bearings. Bulletin.
Standard Steel Corp.

5A Continuous Centrifugals
Instantaneous selection beach speed from 0 to 300 in. per min. Choice of seven different pool depths. Literature.
Tolhurst Centrifugals Div., American Machine and Metals, Inc.

6A Gate Valves
Exelloy trim for oil and oil vapor services. Sizes 2 to 24 in.; screwed, flanged, welding ends. Catalog.
Crane Co.

7A Heat Transfer Medium
Dowtherm for chemical, paint, petroleum, food and other process industries.
Dow Chemical Co.

8L Acid-Proof Metal
Tantalum, for most acid solutions and corrosive gases or vapors except HF, alkalis, or substances containing free SO_3.
Fansteel Metallurgical Corp.

9A Processing Kettles
Available in research laboratory to test new processes and new products. Kettles perform a number of basic operations; heating, cooling, mixing, extracting, reacting, distilling, evaporating, drying, and solvent recovery. Vacuum, atmospheric, or pressure operations can be provided. Booklet.
Buflovak Equipment Division

10A Plug Valves
Teflon or rubber-faced plugs. Made in almost all metals, rubber-lined models, sizes from 1/2 in. to 20 in.
DeZurik Shower Co.

11A Large-Capacity Filters
Vertical and horizontal pressure-leaf filters from 20 to 1500 sq. ft.
Niagara Filters Div., American Machine and Metals, Inc.

12L Wire Cloth
Available in all the commercially used metals. Sizes ranging from 4 in. (space cloth) down to 400 mesh. Catalog E.
Newark Wire Cloth Co.

13A Processing Facilities
Production plants for high-temperature, high-pressure processes, involving corrosive materials.
The Girdler Co.

14A Celite Powders
Absorb up to three times their own weight of liquid. Useful in preventing ammonium nitrate crystals from caking, in absorbing liquid insecticide poisons, and in controlling pitch trouble at paper mills. Information and samples.
Johns-Manville

15A Announcing New Plant
For steam generators, heat-transfer and process equipment.
Foster Wheeler Corp.

16A Proportioning Pump
For additives or chemical reagents. Built-in standard motor—no separate gearbox or couplings. Built-in oil-enclosed gear reducer. Bulletin.
Proportioneers, Inc.

636A Tower Packing
Intalox saddle packing currently available in 1/2 in., 3/4 in., 1 in. and 1 1/2 in. sizes, white chemical porcelain or chemical stoneware.
U. S. Stoneware Co.

19A Filters
Continuous vacuum filter for use in the production of soda ash.
The Eimco Corp.

20A Honeywell Instrumentation
Cabinet dryers are controlled by panel of wet and dry bulb Brown thermometers. Composite catalog.
Minneapolis-Honeywell Regulator Co.

23A Catalytic Cracking Units
Design, engineering, construction for the chemical, petrochemical and oil refining industries.
Catalytic Construction Co.

.24A "Karbate" Equipment
Heat exchangers, cascade coolers, centrifugal pumps, HCL absorbers, pipe and fittings.
National Carbon Co.

27A Sulphur
The role of sulphur in the vulcanization of rubber.
Freeport Sulphur Co.

28A Tank Insulation
Zerolite insulation for outdoor tanks and vessels.
Johns-Manville

29A Vacuum Pumps
Equipped with gas ballast to assist in your water-oil contamination problems. Also high speed, low power pumps for metallurgical processes where large volumes of gases are liberated.
Kinney Manufacturing Co.

31A Piston-Diaphragm Pump
Diaphragm isolates chemical being pumped from working pump parts. Variable flow results from variation in piston-stroke length. Bulletin.
Lapp Insulator Co., Inc.

33A Chemicals from Coal Hydrogenation
Award for "the first successful production of chemicals from coal by a high pressure hydrogenation process." Chemicals used in making plastics, synthetic rubber, pharmaceuticals, vitamins, and many other things.
Union Carbide & Carbon Corp.

34A Valves
Features various valve installations in a Celanese processing plant.
Hammel-Dahl Co.

43A Graphite Anodes
Graphite anodes for the electrolytic industry in making chlorine and caustic soda for antiknock compounds.
Great Lakes Carbon Corp., Electrode Div.

45A   Evaporators
Flat plate evaporators. Long tube film type evaporators.
Process Equipment Div., General American Transportation Corp.

46L   Compressors
To compress air or gas free of any trace of oil or oily vapors. Bulletin.
Pennsylvania Pump & Compressor Co.

47A   Process Cooling
Chilled water from a single package suited to electroplating, metal quenching, die cooling, rubber mixing.
The Trane Co.

49R   Filtration
Engineering and equipment. Sizes from 100 sq. ft. to 2,000 sq. ft. of filtering surface.
Sparkler Manufacturing Co.

50L   Double Arm Mixers
Provide thorough dispersion of ingredients in pharmaceutical compounds. Available in capacities up to 750 gal.
Read Standard Corp.

51A   Water Treatment
Conventional and high-rate units for every water treatment problem. Bulletin.
The Dorr Co.

53A   Stainless Tubing
Seamless or welded stainless tubing in any number of grades, in a broad size range.
The Babcock & Wilcox Co., Tubular Products Div.

PRODUCTS (Continued)

54L   Technical Molybdenum Trioxide
The raw material for the production of all molybdenum compounds.
Climax Molybdenum Co.

55A   Sealless Pumps
No stuffing boxes, no lubrication. Available in 1/3, 3/4, 1, 2, and 3 horsepower sizes.
Chempump Corp.

57A   Durcopumps
For heavy-duty chemical service, high silicon iron or stainless steel alloy to fit your corrosion problem. Bulletin.
The Duriron Co.

58L   Antifoam
Silicone defoamer in recirculating cooling brines, bottling soft drinks, varnish cooking, textile resin backings, and steel pickling baths. Free sample.
Dow Corning Corp.

58BR   Spraco Nozzles
Full cone, flat spray and hollow cone spray nozzles. Catalog.
Spray Engineering Co.

59R   Fume Washers
For difficult gas and fume elimination problems under extremely corrosive conditions.
Maurice A. Knight

61R   Color Comparators
For phosphate, pH, chlorine determinations. 96 page book.
W. A. Taylor and Co.

63A   Pyrex Cascade Coolers
Resistant to virtually all acids (except hydrofluoric) and mild alkalies. Also pipe, fractionating columns and other plant equipment.
Corning Glass Works

64L   Paracoil Heat Exchangers
Special equipment, pilot plant units or plant modernization programs.
Davis Engineering Corp.

65T   Special Filtering Problems
Packaged plant for continuous filtration of molten phosphorus. Also standard filtering problems. Bulletin.
R. P. Adams Co., Inc.

65B   Proportioning Pumps
7,500, 15,000 or 30,000 lb./sq.in. working pressure by the interchange of piston and cylinder assemblies. Bulletins.
American Instrument Co., Inc.

66T   Industrial Balances
Micrometer-poise balance for speedy determination of weight.
Ohaus Scale Corp.

66B   Process Piping
Fabricated from complete range of alloys, any diameter up to 60 in., and in any shape.
The Pressed Steel Co.

67R   Polyethylene Pumps
Fluid contacts only outer surface of molded flexible liner and inside of pump body block. From fractional to 20 gal./min.
Vanton Pump and Equipment Corp.

68L   Air Classifying Systems
With a Hardinge superfine classifier, a 99 1/2% passing 325 mesh product is obtainable. Also makes tricone, tube and rod mills. Bulletin.
Hardinge Co., Inc.

69T   Furane Resin Cement
A mortar for corrosion-resistant masonry. Folder.
Delrac Corp.

69B   Nicholson Traps
Five types for every application, process, heat, power. Sizes 1/4 in. to 2 in.; pressures to 250 lb.
W. H. Nicholson & Co.

71R   Vitreous Silica Tubing
Chemically inert tubing, available in four qualities: transparent, sand surface, glazed, and satin surface. Bulletin.
The Thermal Syndicate Ltd.

72T   Pumps
To handle abrasive, corrosive, thick or hot liquids.
Nagle Pumps, Inc.

72B   Laboratory Planning
"Labritecture" offers a basic method in laboratory planning, modernization, and expansion. Catalog.
Metalab Equipment Corp.

73TR   Temperature Controls
High temperature safety alarm or cut-out. Ranges from −300° F. to + 1800° F., electric or pneumatic.
Burling Instrument Co.

73BR   Evactors
Steam jet vacuum units provide pressures ranging from a few inches to a few microns.
Croll-Reynolds Co., Inc.

IBC   Chemical and Process Equipment
Towers, heat exchangers, pressure vessels and special piping.
The Vulcan Copper & Supply Co.

OBC   Mixing Equipment
Laboratory, portable, top entering, side entering mixers. Catalogs.
Mixing Equipment Co., Inc.

CHEMICALS

Vyflex. Rigid polyvinyl chloride, Vyflex, containing organic-type stabilizer. High strength, resistance to corrosion. Lends itself to sawing, turning, drilling, vacuum forming. Can be fabricated by hot-gas welding. Kaykor Industries, Inc., Division of Kaye-Tex Mfg. Corp.
1

Industrial Chemicals. Bulletin from Commercial Solvents Corp. lists fifty-two industrial chemicals, formulas, physical properties, uses, etc.
2

Hydroxyethyl Cellulose. Powder form of Cellosize hydroxyethyl cellulose commercially available from Carbide and Carbon Chemicals Co. White, water soluble, used as thickener, stabilizer, dispersant, binder. Two viscosity types.
3

Chemicals Wall Chart. Wall chart, showing composition & specifications of standard Chemi-Fats produced by Archer-Daniels-Midland Co.
4

Polyvinyl Chloride. Rigid, unplasticized polyvinyl chloride from Hartwell Co. Sheets, bars, pipe & fittings, other fabrications. Folder gives various properties, applications, sizes, other data.
5

Lithium. Guide book on lithium & its compounds from Foote Mineral Co. Illustrated, gives analysis of each compound, uses, other pertinent information. — 6

Polyvinyl Chloride. Rigid polyvinyl chloride, Hysol 9000 series, announced by Houghton Laboratories, Inc. Uses include fabricated piping, tubing, duct work, work tables, sinks. Folder lists properties. — 7

Aqueous Enamels. Reichhold Chemicals, Inc. water-soluble resin capable of being heat dried. Composed of phenol alcohol, an alkyd resin, & ammonia. Permits thinning with water & application directly to metallic surface, clear or pigmented. Bulletin. — 8

Pickling Process. Nielco Laboratories, Ferr-O-Niel pickling process. Specially developed pickling acids & continuous pickling without special disposal system. Eliminates pollution, corrosion, hazardous fumes. — 9

Glycol Ethers. Ansul Chemical Co. glycol ether pamphlet. All pertinent data plus information on analytical procedures. — 10

Filteraid. Carbon filtered, Nerofil, developed by Great Lakes Carbon Corp. for filtration of alkaline solutions. Free-flowing black powder yielding wet filter cake of 18-21 lb./cu.ft. density. High porosity & permeability plus resistance to alkaline solutions. Combustibility simplifies filter-cake disposal. — 11

Resin Cement. Furane resin cement, Resiment, for acid brick or tile mortar in corrosion-resistant tank linings, floors, sewers, towers, etc. Low porosity, high compressive & tensile strength, resistant to impact & abrasion. Richards & Webb, Inc. — 12

Acid Proofing. Brush or trowel application of phenolic resin to corrosion-proof concrete against acid & alkali. Available in color, resists heat, other advantages. Leaflet. Carboline Co. — 14

Vulcafilm. From B. F. Goodrich Co., Vulcafilm rubber film. Can be electronically sealed to itself; combined with various fabric reinforcements. Compound may be varied to resist oil, gasoline, sunlight, heat, cold, abrasion or acids. — 15

Rust Inhibitor. Rust-inhibiting oil additive for protection to ferrous surfaces, available in commercial quantities from Atlas Powder Co. Protects stored equipment and machinery as well as those in use. — 16

BULLETINS

Pumps. For circulating and boosting water and other clear liquids at medium and high heads, pumps from Peerless Pump Division. Available in 2- to 5-stage designs; head ranges to 1550 ft.; capacities to 300 gal./min.; liquid temperatures to 300° F. Bulletin. — 21

Stainless Steel Equipment. Tanks fabricated from stainless steel for textile, paper, chemical and other industries from Rodney Hunt Machine Co. Bulletin lists sizes, diagrams, and illustrations. — 22

Industrial-Regional Development. Arthur D. Little, Inc. folder on programs for industrial-regional development. — 23

Waste Treatment. From Minneapolis-Honeywell Regulator Co. catalog devoted to instrumentation for water, sewage, and industrial waste. Illustrated. Sections on treatment processes requiring instrumentation. — 24

Dust Control. Dracco Corp. A 40-page product bulletin covers industrial dust control and recovery. Presents technical information and data on solution of industrial dust collection problems. Specifications on five types. — 25

Valves. Catalog covering needle, globe, plug, check, relief, and special valves from Republic Mfg. Co. Added are gauge protectors and snubbers, bleeders, etc. Units made of brass, bronze, steel, stainless and aluminum alloy for instrumentation, aircraft, processing industries. — 26

Solenoid Valves. Covering 4-way packless poppet-type solenoid valve, bulletin from Automatic Switch Co. For applications demanding high-speed operation. General description, schematic drawings, etc. — 27

Immersion Heaters. Immersion heater for heating noncorrosive liquids and mixtures. Also acid tank heater featuring noncorrosive fused quartz body.' Clepco-Glorod catalog with power calculating data. Cleveland Process Co. — 28

Engineering Handbook. Taylor Forge & Pipe Works offers 46-page book designed for use by engineers and designers with piping and pressure vessel problems. Sections on products, codes and standards, stresses, values. — 29

Liquid-Level Gauges. Bulletin on line of electronic remote reading liquid-level equipment from Vapor Recovery Systems Co. Receivers in 36-, 48-, and 60-tank-capacity models. Schematic drawings, illustrations, details. — 30

Turba Film Evaporator. Bulletin on the Rodney Hunt Machine Co. Turba Film evaporator. Charts and illustrations explain use, dimensions and operation of unit. Five models plus portable laboratory unit. Concentrates, distills, deodorizes, degasses, deaerates. Liquids, gases, slurries. — 31

Conveying and Mixing Equipment. Link-Belt Co. publication on conveying and mixing equipment for chemical flocculation at water, sewage, and industrial waste treatment plants. Layouts and selection tables. — 32

Welded Floats. W. H. Nicholson & Co. welded floats of stainless, Monel- and chrome-plated steel in variety of shapes and sizes. Folder. Weights, buoyancies, pressures, and other information. — 33

Package Conveyor. A. B. Farquhar division of Oliver Corp. conveyors for handling all types of materials. Illustrated bulletin shows and describes all models, gives details and cutaway views. — 34

Extruded Plastic Parts. Thermoplastic parts including ethocel, Lucite, styrene, nylon, etc., from Anchor Plastics Co. Brochure on applications of rods, tubes and shapes, sections on range and size and fabrication facilities. For designers and engineers. — 35

Plastic Parts. Machined plastic parts of polystyrene, Teflon, formica, Kel-F and nylon from Tri-Point Mfg. & Developing Co. Folder gives details. — 36

Grinding & Pulverizing Machinery. Abbé Engineering Co. complete catalog binder of various products for pulverizing, grinding, dispersing, mixing, etc. Illustrated, descriptions, & data. — 37

Mechanical Conveyors. Jeffrey Mfg. Co. mechanical-vibrating conveyors for feeding, conveying, other process operations. For use where belt, spiral, & other mechanical conveyors are not adaptable. Handles hot & abrasive materials. Illustrated bulletin. — 38

39 **Reference Manual.** Benjamin Foster Co. reference manual describing thirty-six Foster coatings & adhesives for industrial insulations. Technical data, recommended uses. For engineers working with thermal installations.

40 **Trojan Loadster.** Leaflet from Contractors Machinery Co., Inc. on Trojan loadster for traveling, dumping & loading operations. Bucket action. Specifications, dimensional diagram, other details.

41 **Adjustable-Speed Drive.** Reliance Electric & Engineering Co. From ¾ to 3-hp. drive for powering small industrial equipment. For designers of small machines, process engineers, production men. Bulletin features eleven typical applications.

42 **Techlopedia.** From Techniflex Corp., Techlopedia, monthly encyclopedia of technical information. Contains important discussions & mathematical analyses on process & design problems.

43 **Packings.** Mechanical goods division of United States Rubber Co. catalog on installation & care of packings. Selection tables, metric engineering & conversion charts.

44 45 **Electrical Equipment.** (44) Power for electrolytic processes, subject of a booklet from Westinghouse Electric Corp. Selection of conversion equipment, operating voltage, and other pertinent details. (45) Ignition Rectifiers. Illustrated bulletin details required information, gives schematic drawings, etc.

46 **Pump Drive.** Johnson Gear & Mfg. Co., Ltd. right-angle turbine pump drive. Bulletin gives views, features, & other products.

47 **Control Valves.** Shear-Seal fluid control valves from Barksdale Valves. Illustrated folder gives detailed description, diagrams, sizes, etc. For water, air, hydraulic oil, fuel, gas, petroleum.

48 49 **TM DorrClone.** (48) The Dorr Co. announces the TM Dorr-Clone. Cylindro-conical classification unit utilizing centrifugal force instead of gravity. Separations in the 2-to-20-μ range. Sectional elevation drawings & pictures of individual components of unit. (49) Leaflet on Fluosolids Roasting of Zinc Concentrates, describes a new method of roasting concentrates for electrolytic or retort zinc production.

50 **Filter Cloth.** National Filter Media Corp. has assembled booklet on filter cloths. Pages on cotton, Orlon, Vincel, Dynel-Nylon, other filter cloths. Details characteristics, physical properties, applications.

51 **Angle Valves.** Bulletin on Venturiflo angle valves from Hammel-Dahl Co. Handle viscous fluids, slurries, dirty solutions. No seat ring bridge. Gives valve capacity close to that of line. Illustrated folder gives dimensions, details of construction, schematic diagram.

52 **Mechanical Seal.** Byron Jackson Co. line of mechanical seals. Single, double, balanced or unbalanced seals. Complete descriptions, schematic drawings of each type of seal & accessories. Also shows installations in pumps.

53 **Conveying Systems.** Fuller-Kinyon conveying systems from Fuller Co. Used for conveying from pulverizer mills or collector conveyors to storage or packer bins; loading & unloading cars, ships, barges. Also for mixing & blending dry-cement raw materials.

54 **Gate Valves.** Vernon Tool Co., Ltd. announces gate valves by its Greenwood Valve Division. Line blind valves has metal seats between gate & valve body, forming positive shutoff. O-rings of synthetic rubber meet petroleum Inc. Available with flanged or welding ends. For liquid requirements. Cast steel & built to A.S.A. specifications.

55 **Pipe Protection.** For all exposures, Hill, Hubbell and Co. coat & wrap pipe to specification. Illustrated folder shows & describes steps in process.

56 **Expansion Joints.** Packless expansion joint rigid against all movement except axial, American District Steam Co., Inc. Available with flanged or welding ends. For liquid & gas lines in petroleum & chemical processing plants, factories, power plants, etc. Illustrated folder.

57 **Jacketed Fittings.** Red Jacket Co., Inc. fittings & pipe jacketed with carbon molybdenum, chrome steels, chrome nickel steel, Monel, & nickel. Illustrated pages on each part, plus tables of sizes, weights, etc., in folder. Diagrams of individual types.

58 **Specialized Equipment.** For chemical petroleum, gas, & power industries, specialized equipment manufactured by J. F. Pritchard & Co. Cooling towers, heat exchangers, gas & air-treating equipment. Bulletin also covers design, engineering, construction & processing services.

59 **Diesel Engines.** Nordberg Mfg. Co. type TS-21 Diesel engines. Sizes from 2,550 hp., 1,800 kw. to 6,150 hp., 4,400 kw.

60 **Oil Filter.** Loose-leaf catalog from Purolator Products, Inc. illustrates products, includes specifications & other data sheets on individual products in line for use in all types of motor vehicles.

61 **Agitator Drives.** Pacific Western vertical agitator drives — double & triple reduction for 24-hr. heavy-duty service. Table of horsepower ratings, diagrams of various models. For agriculture, food, paint, paper, textile, etc. industries.

62 **Industrial Mixers.** Multiduty, batch & other mixers, & side-entry agitators, of Conn and Co. Illustrated folder lists applications, available sizes of each item, other data.

63 **Metal Products.** Littleford Bros., Inc. fabricators of plate & sheet metal products of carbon or stainless steel, aluminum, & other alloys. Bulletin.

64 **Water Softeners.** Folder from Illinois Water Treatment Co. on green sand, zeolite, water softeners. Details on composition, applications, selection table on types.

65 **Laboratory Pump.** Eco Engineering Co. pumps for laboratories or pilot plants. Small volume feeding, for pressures to 150 lb./sq.in. Positive—displacement type. Two sizes, ⅜ in. ports & ½ or ¾ in. ports. For clear viscous fluids, emulsions & solutions. All Chem pump in all Teflon & stainless steel.

66 **Wire Cloth.** Plain, Twill, Dutch, or special weaves in all metals & finishes. Fine wire cloth 10 to 325 × 325 mesh. Unique Wire Weaving Co., Inc.

67 **Gaskets & Accessories.** Fabricated from Teflon & impervious to chemicals other than molten alkaline metals, fluorine, & chlorine trifluoride. For chemical, pharmaceutical, or food production. Folder describes design, products, other pertinent information. United States Gasket Co.

68 **Measuring Equipment.** General Electric Co. revised 64-page catalog of measuring equipment. Indicators, oscillographs; surface roughness scale, mass spectrometers; d-c amplifiers, radiation monitors, etc. Description of each product, application, tables of characteristics.

69 **Oxygen-Measuring Equipment.** Leeds & Northrup Co. equipment for oxygen-measuring problems. Records, aids in maintaining correct O_2 for combustion, & in various operations. Accuracy to $\pm 0.05\%$ permits precise analysis of operation.

70 **Floor Gratings.** Variety of floor gratings & safety steps in steel, aluminum, stainless, & other alloys. Illustrated catalog gives ordering suggestions, specifications, cutaway views, construction details. Borden Metal Products Co.

71 **Centrifugal Separators.** Catalog of A. W. Bannister Co., Inc. Dustmaster centrifugal separators. Remove dusts, decrease maintenance costs, increase productivity. Also as precleaners for filters & electric precipitators. Cutaway views, tables, etc.

72 **Laboratory Flowmeters.** Specification sheet from Potter Aeronautical Co. on laboratory flowmeter systems. Variety of types illustrated. Operating principle, specifications given.

73 **Regulators.** Catalog of pressure & temperatue regulators, self-cleaning strainers. Spence Engineering Co., Inc. Two-color cutaway views, selection hints, pipe flow formulas, capacity tables, flange standards. Service steam, air, gases, water, other liquids.

74 **Radiant-Convection Furnaces.** Petro-Chem Development Co. describes the Isoflow radiant-convection-type furnace. Design is upright cylindrical steel structure with integral self-supporting stack. Even radiant-heat distribution, increases flue gas velocity at upper section.

75 **Laboratory Press.** Small-scale tests in research & development operations. Fred S. Carver, Inc. laboratory press. For general use with various types of auxiliary equipment & parts. Also 20-ton & laminating presses, & items of specialization.

76 **High-Vacuum Pumps.** Binder insert catalog from International Pump & Machinery Works on high-vacuum pumps. Specification sheets on each type made. Pumps feature speed, production, reduced maintenance. Simply constructed, lubrication is automatic.

EQUIPMENT

80 **Stress Data.** For engineers designing or operating tubular equipment at elevated temperatures & pressures. Data card shows maximum allowable stress values for complete range of seamless & welded carbon, alloy & stainless steel tubing & pipe. Adaptation of new A.S.M.E. boiler code. Babcock & Wilcox Co.

81 **Recording Turbidimeter.** For automatic measurement & recording of number of particles suspended in liquids, recording turbidimeter from General Electric Co. Used with audible or visible alarm wherever turbidity is a factor. Adjustable over wide range, splash-proof construction. Semi-null balance system.

82 **Gas Generator.** Announced by Baker & Co., Inc., redesign of Nitroneal gas generator for production of nitrogen. Lowers gas dew point from $+75°$ F. to $+40°$ F., permitting less expensive driers. Reacts ammonia with air in presence of catalyst.

83 **Storage Tanks.** Aluminum Co. of America new standard tanks for storing materials at atmospheric or low pressure. Capacity range 5,800 to 16,400 gal.; horizontal & vertical types; 10-ft. diam. Made from $\frac{1}{4}$ in. welded 3-S aluminum alloy.

84 **Centrifugal Pump.** A solid plastic centrifugal pump from Mission Mfg. Co. Formed of phenol-formaldehyde resin or furfuryl alcohol resin & inert filler of asbestos or graphite. Handles acids, bases, salts, solvents, other chemicals. Solid plastic concentric casing with solid plastic semi-open impeller.

85 **Linear Position Transducer.** North American Instruments Inc. Northam linear position transducer. Converts linear motion or position into proportional electrical signal or remote indication or control.

86 **Compressors.** Pennsylvania Pump and Compressor Co. sectionalized cylinders for air & gas compressors. Arranged in three pieces, has inlet & discharge valves in fronthead & backhead. Easily disassembled, liner may be removed without disconnecting inlet or discharge air piping.

87 **Dehumidifiers.** Vi-Speed dehumidifiers. Self-adjusting nozzle coupled with nonclogging aspirator. Stabilizes unit during variable air pressures & volumes for constant removal of injurious liquids, solids, other contaminants. Brochure available. Van Products Co.

88 **Metal Data Sheets.** Wall Colmonoy Corp. series of data sheets for the chemical industry. Application of Colmonoy nickel-base & iron-base hard facing & Spraywelding alloys resistant to corrosion, abrasion, impact & galling.

89 **Arc Welding.** Reference table for fabricators of tubular materials, published by Babcock & Wilcox Co. Details for joining similar & dissimilar alloys by arc welding. Covers carbon, intermediate chromium molybdenum alloy steels, etc.

90 **Water Heaters.** Three series of cylinder-type & two series of table-type automatic electric water heaters from Servel, Inc. Capacities 30 to 80 gal. according to type. One or two heating elements.

91 **Oxygen & Combustibles Analyzer.** Bailey Meter Co. combination oxygen & combustibles analyzer for information on combustion. Acts as safety guide to prevent lighting off of unpurged gas-fired combustion chambers. Analyzes $\%O_2$ & $\%$ combustible.

92 **Relief Valve.** From Eclipse Fuel Engineering Co. piston-type, oil relief valve for regulating pressure on closed flame gas-oil burners. Eliminates chattering & pulsation.

93 **Rotary Feeder Air Lock.** For handling bulk material under high pressure or vacuum in the chemical & food-processing industries, rotary feeder air lock available in cast iron, stainless steel, or Monel from Hening & Co. Seal may be spring loaded, of neoprene, rawhide, asbestos, or Teflon, run dry or lubricated as required. Rotor has six pockets or more, vanes are hard surfaced.

94 **Packaged Unit Spray Dryers.** Packaged unit spray dryers offered by Foster D. Snell, Inc. Revised edition of booklet shows diagrams of conventional drying compared to spray drying.

95 **Pressure Feeder.** Individually designed differential pressure feeder from John T. Collins & Co. For free-flowing or slow-moving materials. Gates & chokes open automatically. When mechanically closed, gates are locked & sealed against loss of pressure or vacuum. Carbon or stainless steel.

96 **Viscosity Control.** For automatic, instant, & continuous measuring, recording, & control of viscosity, Ultra-Viscoson. Folder lists features, describes operating method; specific applications. Bendix Aviation Corp.

97 **Industrial Pump.** For general industrial service Ajax Iron Works pump, 200 to 400 rev./min. Delivers 12.5 gal./min. at 100 rev./min.; to 50 gal.min. at 400 rev./min. maximum pressure 2,050 lb./sq.in. Fluid end sectionalized & separate from power end.

98 **Temperature Controls.** For measurement of dynamic pressures at extreme temperatures, Control Engineering Corp. water-cooled pressure pickup. Can be exposed to gas temperatures of + 5,000° F. without damage. Heat transfer rate for entire face of unit is 11 B.t.u./(sq.in.)(sec.) with cooling water temperature rise of 85° F. Exposed parts stainless steel.

99 **Analog Computer.** From Berkeley division of Beckman Instruments, Inc. Ease analog computer. Simulates electronically, physical systems. Either theoretical or empirical formula set up in computers. Uses variation of coefficient potentiometers.

100 **Ultracentrifuge Cell.** For measuring sedimentation constant of slow component moving in presence of a fast one, new Spinco synthetic-boundary ultracentrifuge cell. Extends range of ultracentrifugal analysis down to molecular weight of about 10,000. Specialized Instruments Corp.

101 **Pneumatic Conveying System.** Unit for handling bulk materials from Sprout, Waldron & Co., Inc., Pneu-Vac, a draw-through system. Fan mounted on top of long-cone collector. Rotary-vane feeder-valve at base of collector. Individually engineered. Bulletin supplies details.

102 **Spectrograph.** Bausch & Lomb Optical Co. A 1.5 meter stigmatic grating spectrograph for use in small firms, hospitals, colleges, high schools. Two models provide different dispersions, resolving powers, plate coverages. Analyzes nonferrous materials. Also suitable for complex spectra of unalloyed gray irons, etc.

103 **Sigmamotor Pump.** Larger model Sigmamotor pump to handle tubing to 1-in. diam. Hinged top permits tubing to be placed against fingers for pumping without disconnecting either end. Pumps liquids, gases, or solids in solution, 45 to 250 gal./hr. at 500 rev./min. Handles corrosive liquids or liquids with abrasives in solution.

104 **Sealing Ribbons.** Bulletin from Minnesota Mining & Mfg. Co. covers weatherproof, watertight, synthetic rubber fabric-reinforced sealing ribbons. Available in 100- & 200-ft. rolls. Data on specifications for thirteen sizes from ¼ to 2 in. wide and 1/32 & 1/16 in. thick.

105 **Liquid Level Control.** Instruments, Inc. announces controller giving on-off signal with level rise. Works with viscous fluids. Detects liquid or foam level; sensitivity adjustment permits reaction to or ignoring of foam. Self-contained except for probe. Cables from 52 to 100 ft.

106 **Overload Device.** Lamson Corp. device protects chain drives from overload by tripping limit switch when tension on drive leg occurs. For process engineers in metal working, chemical, food, paper, & textile industries.

107 **Thermo Electronic Recorder.** Thermo Electric Co., Inc. thermo electronic recorder—potentiometer pyrometer & resistance thermometer bridge types. Ranges from − 100° to + 3,000° F. Also suitable for recording humidity, solution conductivity, speed, pH, etc.

108 **Electrivolume Meter System.** Buffalo Meter Co. introduces Niagara Electrivolume metering system for flow measurement. Designed for particular liquid base, cold & hot water base, viscous or nonviscous. Also corrosive chemicals. Catalog available.

109 **Nylon Filter Cloths.** Nylon filter cloths of high tensile & bursting strengths, light weight, & minimum shrinkage. Replaces 10-ply cotton cloth. Available to 90 in. wide, in any desired length. Robert Brautigam Sons.

110 **Corrosion-Resistant Pump.** Vanton Pump Corp. new series pumps utilize buna N hard rubber body block for temperatures to 225° F. Resistant to corrosive acids, caustics, & organic solvents. Eliminates stuffing boxes & shaft seals, check valves, & gaskets. 1/3 to 20 gal./min., pressures 0 to 60 lb./sq.in.

111 **Automatic Graph Plotting.** From International Business Machines Corp. an automatic graph plotting booklet. Describes how wheel printing feature of IBM type 407 machine is utilized for plotting graphs from information punched on IBM cards.

112 **Time-Temperature Controller.** Bristol Co. recording potentiometers as time-temperature program controllers. Regulate temperature predetermined according to schedule of changing values. Heating, cooking, or soaking cycle accurately maintained. Temperature schedule prescribed by contour of transport plastic cam.

114 **Sump Pump.** Folder on 1½ in. Galigher Co. acidproof sump pump. Handles acid sludges, corrosive & foamy products with solids in suspension. Also pumping where heads to 35 ft. & flows to 75 gal./min. are required. Operates till sump level falls below lower suction cover. Empties tanks to 2½ in. from bottom. Neoprene & special rubber compounds available.

115 **Thermocouple Head.** Newly designed thermocouple head announced by Claud S. Gordon Co. Installation & service conveniences. Temperatures to 900° F. in continuous service. Binder page insert gives other details.

116 **Miniature Indicators.** Fischer & Porter Co. describes construction, installation, & design features of remote miniature indicator in bulletin. Over-all height of indicator face 5¼ in.; scale 5¾ in. long. Method of setting up control transfer station; other pertinent data.

117 **Vibrating Feeder.** Vibrating solids feeder with extra-wide range of outputs from Richardson Scale Co. Turns out 1 to 20 cu.ft./min. of grain, feed, rock, fertilizer, chemical products. Motor ⅛ hp. Feed rate controlled by hand lever.

MONSANTO TO PRODUCE POLYETHYLENE IN TEXAS

The first polyethylene production plant to be built by Monsanto Chemical Co. will be situated at Texas City, Texas, according to a recent announcement by Robert K. Mueller, general manager of the Plastics Division.

Expected to be on production by the end of 1954, the plant will have an estimated capacity of 66 million lb., which will increase by 50% in 1957.

Ethylene, the raw material for this production, will be supplied by Monsanto's existing Texas Division, which produces styrene, vinyl chloride, and acrylonitrile at this location.

CHEMICAL ENGINEERS MEET IN GERMANY

About seven hundred German engineers participated last month in the annual chemical engineering conference, at Karlsruhe, sponsored by the technical societies V.D.I., D.E.C.H.E.M.A., and V.D.M.A. Held in conjunction with the celebration of the twenty-fifth anniversary of the founding at Karlsruhe of Germany's first institute for research and instruction in chemical engineering, the convention offered papers on heat transfer, drying, brittleness, grinding, dimensional analysis, flow problems, absorption, scale and crust formation, rectification, reaction apparatus, and problems in the construction of the German Buna Rubber plants.

The papers will be published in forthcoming issues of Chemie Ingenieur Technik and Forschung auf dem Gebiet des Ingenieur-Wesens and in a pamphlet issued by D.E.C.H.E.M.A.

STATISTICAL CONCEPTS COURSE AT RALEIGH, N. C.

A special program of course work, lectures and seminars on statistics for research engineers, physicists, and chemists will be sponsored by the Institute of Statistics of the University of North Carolina during the spring quarter of 1954 (March 24 to June 4). The primary objective of this program is to provide an opportunity for industrial research workers to acquire a working knowledge of modern statistical concepts and techniques. Emphasis will be on the efficient design of experiments and the analysis of data therefrom. Informal seminars on statistical problems submitted by the participating students will be held. Regular college credit will be granted for course work satisfactorily completed.

Guest lecturers will include Drs. W. J. Youden and M. G. Kendall.

For further information write to Institute of Statistics, North Carolina State College, Box 5457, Raleigh, N. C.

WOMEN ENGINEERS TO MEET IN WASHINGTON

The national convention of the Society of Women Engineers will be held in Washington, D. C., on March 5 through 7, 1954.

The theme of the meetings will be "The Woman Engineer's Contribution in a Peacetime Economy," and discussions will be held from the point of view of transportation, communications, home improvement, and machinery.

Trips have been planned to the National Bureau of Standards, David M. Taylor Model Basin, and U. S. Navy Engineering Experiment Station.

Inquiries can be sent to Ethel Levene, 504 Winthrop House, Washington 6, D. C.

TEACH-THE-TEACHER PROGRAM AT MEMPHIS

A "Teach-the-Teachers" program held in Memphis, Tenn., last month as part of the activity of the Chemical Engineering Education Projects Committee of A.I.Ch.E. benefited from the experience of two firms operating in the vegetable-oil industry, according to Dr. Frank A. Anderson, chairman, department of chemistry and chemical engineering of the University of Mississippi.

The school was organized by M. Foster Moose, professor of chemistry at Southwestern College, Memphis, Tenn., and was attended by twenty-one chemical engineering and chemistry teachers from the University of Mississippi, Memphis State College, Chrisian Brothers College (Memphis), Southwestern at Memphis, Murray State College, Kentucky, and Florence State Teachers College, Alabama.

After a morning of talks by William Lassetter, editor of The Progressive Farmer; Otto Alderks, Buckeye Cotton Oil Co.; and William F. Schroeder, Humko Co., the group toured the Hollywood solvent extraction plant of the Buckeye Cotton Oil Co. (the first time that the plant has been opened to visitors) and the Humko Co. The subject of the conference was the processing, refining, and marketing of vegetable and cotton-seed oils.

NEW TITANIUM PLANT TO ADD TO U. S. OUTPUT

A $25,000,000 titanium plant will be erected by Cramet, Inc., wholly owned subsidiary of Crane Co. of Chicago, according to a recent announcement. The new plant, it is reported, will increase national production of titanium sponge by 6,000 tons annually. Partial production is scheduled for 1954 and full production a year later.

Production will include ingots of titanium and titanium alloys as well as sponge. A large part of the initial output will be allotted directly and indirectly to the Air Force.

Management of the new construction will be handled by Vitro Corporation of America.

CANADA WILL HAVE NEW SYNTHETIC FIBER PLANT

Construction of a $20 million plant for the manufacture of Terylene, a synthetic polyester fiber, has been announced by Imperial Chemical Industries, Ltd., of Canada. The plant, which is being built by The H. K. Ferguson Co., will be located at Millhaven, Ont., about 13 miles west of Kingston; completion is expected early in 1955.

ORGANIC RESEARCH CENTER FOR ALLIED CHEMICAL & DYE CORP.

The new organic research laboratory and development center of the Nitrogen Division of Allied Chemical & Dye Corp. was opened last month in Hopewell, Va. Built at a cost of $1 million, the unit provides some 40,000 sq.ft. of working space adjacent to the company's ammonia laboratory. Two buildings house the laboratories, engineering staff, and experimental units. An installation over the main entrances contains apparatus for automatically distilling water for laboratory use. Products of the Nitrogen Division include anhydrous ammonia, sodium nitrate, ammonium nitrate limestone, urea, ammonia, ammonium nitrate and urea solutions, high-analysis complete fertilizer, methanol, formaldehyde, chlorine, and ethylene oxide and glycol.

Private vs. Public Control of Atomic Energy Discussed at N. I. C. B. Meeting

"The important thing is to provide legislation which will be an incentive for private capital to assume part of the load of exploration in the field of nuclear power but which will not constitute a legislative straitjacket to technological development," Eugene M. Zuckert, member, U. S. Atomic Energy Commission, told the second annual conference on atomic energy in industry sponsored by the National Industrial Conference Board in New York recently.

Another viewpoint was presented by Chet Holifield, Congressman and member, Joint Atomic Energy Committee, who said, "I am opposed to amendments which would alter the basic philosophy and concept of government responsibility as outlined in the Atomic Energy Act."

"Any changes to be made," Congressman Holifield continued, "must take into full account the role of atomic energy in national defense, the special problems of atomic security and inventory control, the responsibilities of government to protect the health and safety of the general public, and our obligations—both moral and contractual—to our friends and allies, who are, in a sense, as much affected by all that we do as are the citizens of these United States.

"The success of our efforts in this direction requires a constant and vivid awareness of our dependence on foreign ore receipts for the full-scale operation of our vast atomic program. Other nations which contract with us to supply uranium accept the basic objectives of our Atomic Energy Program. Were we to make quick and drastic changes in the law which governs this program, or to arouse premature and exaggerated expectations of atomic power benefits under private control, these nations might be less inclined to cooperate. . . . Before we can seriously contemplate the diversion of fissionable material to nonweapon uses, we must be certain that the national security will in nowise be jeopardized."

After a brief résumé of hearings held this summer on atomic power development by the Joint Committee, Representative Holifield concluded, "I believe that the Atomic Energy Commission can take important steps under existing legislation to promote greater industrial participation in the atomic energy program. A healthy sign of active and continued interest on the part of private industry is the formation of industrial teams to work in cooperation with the Commission on atomic power possibilities."

Commissioner Zuckert, continuing the *pro* argument at the round table on changing the Atomic Energy Act, maintained "that legislation is necessary now as a signal of intent of the national policy—a policy which establishes that we wish to do what is necessary in order to attract private capital and private enterprise.

"Any legislation will have to give to the Commission considerable discretion in order that we may be able to move dynamically in response to developments within the industry.

"This does not mean that the Commission will be able to act arbitrarily. There are a great many checks and balances built into the structure of the government. For example, before the Commission could take steps which would involve any large-scale commitment of government funds, its program would have to have approval from both the executive and legislative branches of government."

Other aspects of the use of atomic energy in industry were also considered.

In discussing the safety factor of reactors, John J. Grebe of Dow Chemical Co. explained that control should be inherent in the design, as "the fuel elements being designed to operate at a fairly uniform inner temperature will expand as a result of phase transformation in line with the flow of sodium. Even if some of the fuel should melt, a design can be envisioned in which no harm would be done since we do not count on keeping the primary cooling circuit free from contamination. In fact, if the entire reactor were to melt down and circulate with the sodium, the design can be such that we count on no dangerous situation. We are even hoping to use this technique as a means of removing reactor elements by merely shutting down the flow of cooling sodium to any one element in order to melt it down for reprocessing. . . ."

The use of radioisotopes to improve automatic plant control was described by D. C. Brunton of Isotope Products, Ltd., who said, "In paper making, for example, basis weight is the most important of three process variables. . . . Now for the first time in paper making history, paper machines are put on automatic control. The measurement of basis weight made by the beta gauge is fed back to control the pulp stock flow onto the paper machine."

NATIONAL SURVEY QUESTIONNAIRE

ANALYSIS OF WRITE-INS

(Continued from November)

Lloyd B. Smith, G. E. Montes and J. A. Polack

Economic Status of Engineers

Massachusetts — Serious reservations about the present policy of beating the bushes to get more engineers. Will tend to be more engineers than jobs. What is wrong with the law of supply and demand?

Missouri—Only by adequate remuneration can industry expect the engineers it needs in the future.

Maryland—Recommend throwing out all articles and items about the shortage of engineers unless the articles specify the duty of the engineer in question and the salary at which he is not available.

New York—The drive to get more young people into chemical engineering is overdone. Supply and demand still rule and rightly so.

California — Actively campaign for higher salaries for engineers. Campaign to get engineers out of non-technical positions, i.e., better manpower utilization.

Alabama—Do not receive commensurate pay to other professions. Apprentice programs offer more.

Ohio—Chemical engineers are underpaid. They often earn less than hourly wage earners. An engineer of 8-12 years employment, now in the $5,000-$7,000 bracket, is not receiving double the present day starting rate and should be.

Massachusetts—Salaries in teaching professions are too low.

Tennessee—Financial remuneration is not in line with other professions.[16]

Alabama—Stress welfare of practitioners, not the profession.

California—You are incorrect when you ask for one's "professional income." My company doesn't pay me my rate for "professional services." I probably couldn't earn more than $10,000 practicing chemical engineering profession. We shouldn't give idea chemical engineers are highly paid. It is, however,

[16] Please see survey, August, 1952, C.E.P. and chart of salaries of other professions.

a wonderful stepping stone to management level jobs.

Ohio—A.I.Ch.E. should do everything in its power to raise the economic status of chemical engineers.

Illinois—Institute should take more interest in the individual, especially in such matters as salaries and professional status.

Illinois—A.I.Ch.E. has always been too exclusive. It has had an ostrich-type attitude toward the monetary and social problems of young engineers. It long ago failed to recognize modern trends and take the leadership in protecting the young engineer from becoming the "weak man" between management and labor.

New York—Institute would have a larger membership and more influence if it was oriented to help, protect, encourage, and advance its members, rather than the industry as a whole as now.

Pennsylvania—More emphasis on opportunities in the field rather than comments regarding high starting salaries for new members.

National Meetings

California—Symposia are tops.

Miscellaneous—Have more regional meetings, the annual is too big if more than one hotel is required.

Delaware—Consider only one broad topic at a national meeting.

Oklahoma—I think the movement organizing professional engineers into a union is dangerous and ill-advised. We must set up a group to straighten out these misguided children.

New Jersey—Attempt to get permission to have more members make plant inspections during national meetings.

Ohio—Ask authors of papers to label the parameters on slides. At the 45th meeting this presentation fault was disgraceful.

Ohio—In my opinion, the greatest improvement in technical societies, and the one most badly needed, is stricter supervision and higher standards for manuscripts and papers delivered at conventions. There is 90% trash being produced and published. No one should be allowed to read his paper. What he can't remember is better read than heard anyway.

The Oklahoma Committee on write-in analysis. Standing, left to right: B. J. Ferro, G. E. Hays, W. T. Wise. Seated, left to right: R. E. Sattler, M. F. Wirges, W. J. Wride.

Ohio—The cost of attending meetings has been a matter of some concern to many members, especially juniors whose income is not as large as some of us older active members. The cost of the Awards Banquet has risen to a point where even some of the active members shun it.

Maryland — Consideration should be given to ventilation during sessions.

Illinois—Prefer meetings of special rather than general interest, so that those who cannot attend all meetings can choose those which benefit them most.

Illinois—Cost of regional and national meetings is too high for man not on company expense account.

Illinois—Meetings tend toward too high an academic level.

Pennsylvania—Like well-planned activities arranged for most national and regional meetings.

Tennessee—It is time to consider some subdivisions, such as petroleum, metallurgical, heavy chemicals, etc.[16]

Wisconsin—National meetings should be spread over several sections every year to lower expenses of those attending, especially college professors who must pay their expenses. Suggest the Institute help defray expenses on some such cases where the professors might make worthy contributions.

Canada—Suggest better arrangement for plant trips at national and regional meetings. Present "first come—first served" method is not good.

Washington—National meetings put women completely in a role of necessary nuisances—while giving them a sop of teas, fashion shows, etc. There should be more effort to interest the spouse in the A.I.Ch.E.'s program.

Canada—Suggests a Canadian dinner at meetings of the Institute.

Public Relations

California—Unending effort is needed, both nationally and locally, to enhance the stature of the engineer in public opinion.

Alabama—Join other societies to enhance professional standing, stimulate interest in social and economic problems.

New Jersey—If your public relations were half as effective as those of our medical friends, the profession could have higher caliber recruits.[17]

Kentucky—Doing a very poor job of public relations externally and internally—suggests required reading "Is Anybody Listening?"

Minnesota—Institute doing an excellent job toward better recognition by the public of the role of engineers.

Maryland—Reprints of technical meetings should be sent to Universities for student use. Would serve as good publicity.

Missouri—The majority of the public doesn't have the vaguest idea what a chemical engineer does for a living—or how his work differs from that of a chemist.

Idaho—Public needs more information about the chemical engineer, what he does, and what he is prepared to do.

Pennsylvania—My wife is nervous to have the whole town know I will be away for several days at an A.I.Ch.E. convention and that she will be alone; home town papers should receive this information after the convention.

West Virginia—I take a rather dim view of the Public Relations Committee insofar as it is attempting to publicize the doings of chemical engineers in the eyes of the public. I like this questionnaire. But radio programs, lots of newspaper publicity, A.I.Ch.E. matchbooks, etc., they leave me cold.

New York—P.R. should mainly concern itself with attracting the right kind of new talent. Emphasis should be on the interests and satisfaction of the profession, not on dollars. Help school boys to become aware of type of work available in field. One good man is worth many dollar-hungry duds.

Liberal Arts

California—Question 14 is unfairly "loaded." Liberal arts courses should be stressed more, but not necessarily at the "expense" of technical subjects.

California—More liberal arts should be added to engineering curricula, but not at expense of technical subjects.

New Jersey—Wish I had a chance to take more liberal arts subjects during my undergraduate training but not at the expense of technical subjects. My undergraduate training was only four years. Ch.E. course should be five years with extra year spent on business and liberal arts courses.

West Virginia—Engineers are backward culturally and need more broadening of knowledge.

Licensing of Engineers

Washington, D. C.—In most states professional registration exams and rules are set up so a man just out of school could pass, but a man who is good in his own field could not generally pass the exams.

California—Since we have to accept the fact that registration of engineers is required all over the nation, I would like to see the Institute take a part in gaining reciprocity nationwide.

California—Until a few years ago, a chemical engineer was recognized by his accomplishments and not by act of government. The A.I.Ch.E. should take a stand against the present socialistic movement to make a chemical engineer

QUESTIONNAIRE

(Continued from page 50)

by government fiat and then restrict his activities to one locale.

Ohio—Questions the A.I.Ch.E. should answer for Junior members: (1) how to become registered engineers, (2) what questions are asked, (3) when are exams given and (4) name advantages of registering.[18]

Pennsylvania—A.I.Ch.E. active membership should be so qualified that holders could automatically qualify for registration as P.E. without examination.

West Virginia—I am strongly opposed to state licensing and regulation of engineers and would like to see A.I.Ch.E. take a definite stand against it. Membership in A.I.Ch.E. is a much better indication of competence than any license.

New York—Professional registration, controlled by the Engineering societies, and based on years of practical achievement in one's chosen field, is the only fair and practical way of recognizing professional standing.

Miscellaneous Comments

California—There are many young chemical engineers who do not join the Institute as junior members because of the initial expense required. Could this fee be postponed for several years until the engineer is more or less established? As it is, there is a period after graduation when the engineer does not become associated with the Institute.

Delaware—Dues for local sections should be included in national dues.

Illinois—Eliminate expensive resort locations for meetings where expense is too high for one not on an expense account. Student chapter dues too high, suggest student members with dues at $2-3 per year.

Illinois—Knowing that C.E.P. would cost $6-7 per year, it is difficult to realize what one realizes from the remainder of the $18 dues.[19]

New York—Would like to see in C.E.P., at the end of each year, a financial balance of all monies taken in from dues, contributions, and National meetings, and all monies expended for C.E.P., speakers, postage, salaries, prizes, printing, etc.[20]

California—Suggest A.I.Ch.E. revise and modernize its "Code of Ethics" so as to give specific information about relationship of the engineer to so-called white collar unions, and thoroughly to define what is meant by a "professional engineer" when in private employ.

Oklahoma—Engineers should spend less time talking about recognition as a pro-

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[18] Write me for reprint of symposium on registration; answers 1 and 4.

[19] This is not an answer, merely a fact—It costs $12-$14 a year for each copy of C.E.P.

[20] Audited financial statement is published once a year. See pages 54, 56, June issue. Write if you want more.

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fession and more time working to earn that recognition. The widespread acceptance of stream and air pollution as a necessary evil (for so long a time) is mute testimony for the fact that engineers have scarcely had the public welfare at heart. The studies in "Human Engineering" which have been projected by Carnegie Tech (I believe) are far more relevant, and engineers would be wise to take notice and emulate that approach.

Michigan—A.I.Ch.E. as a professional group should have the highest moral standards. This would give us greater respect and admiration from the public. I would eliminate the cocktail party from the convention.

Ohio—Would like to see more done to further professional recognition in private corporations where, so often, to get to the top of the salary scale one has to stop being an engineer and be an executive.

Illinois—Although professional status is a function of the individual and his own status, ability and interests, a state license gives the professional man legal status. I believe the national professional organizations contribute much more to professional status. What steps can the A.I.Ch.E. take to improve the professional standing of the chemical engineer? I am not familiar with the means used by the American Medical Association in the interest of doctors, and by the American Bar Association in maintaining the profession of law, but they are effective in establishing their respective standings with the public. The problem differs in the case of the chemical engineer, as his status must be maintained largely in the industrial work. His code of ethics is adjusted to this position and his income results from professional services rendered to industry.

Pennsylvania—Unfortunate that engineers have developed a profession in which they are not independent but just another commodity like sulfur or soda. The profession lacks dignity and does not share proportionately to its contribution. A real profession should be started with the University at the center. The intellectual slave market should be abolished where young men are sold into industry at the university. Positions rendering assistance to engineers by people who are not engineers should not be given title of "engineer."

West Virginia—A.I.Ch.E. does little to promote the interests of chemical engineers as do similar organizations in other fields such as the A.M.A.

Alabama—Too much in favor of industry and not individual engineer—need an A.M.A.

New Jersey—Institute should make available to members more information regarding its organization.

New Jersey—Would like to serve on committee but doesn't know how to get started—suggest C.E.P. discuss.[21]

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[21] Every year chairmen of local sections are asked to suggest committee personnel to Secretary of A.I.Ch.E. C.E.P. will also discuss it.

(Continued on page 54)

A LETTER RECEIVED IN QUESTIONNAIRE

Since this is an occasion to complain, I shall do so. Except for one item, I am quite satisfied with the Institute and its publication. However, I object strenuously to the stratification present in the Institute. A man is either a chemical engineer or he is not a chemical engineer. The Institute has a restricted air about it. If we desire to include in its membership the vast majority of chemical engineers, we must become more democratic.

Just what constitutes a responsible position? Every man who is a chemical engineer, regardless of the number of supervisors over him, is in a responsible position. The man who is responsible for decisions made for the most part is not engaged in actual chemical engineering work. If the Institute is an association of administrators, then the name is due for a change.

On any chemical engineering problem no one can say that even the lowest chemical engineer employed is not responsible for success or failure. Decisions made on a top level always depend on accurate and intelligent chemical engineering on the bottom level, where no one engineer supervises any other engineer. The amount of chemical engineering contributed on a given problem many times decreases as one goes from the bottom of the ladder to the top.

The terms junior and associate denote something less than a chemical engineer, and have an unpleasant connotation. If the Institute desires to honor those members who are outstanding in the field, then a definite title or type of membership might be originated. However, this honor should not be such that every other chemical engineer should be referred to as being something less than a chemical engineer. The stratification, in general, makes for a small membership, which in turn severely restricts the service which the Institute desires to fulfill.

To illustrate my point, I have a professional license to practice chemical engineering, two degrees from an Institute-approved school in chemical engineering, an employer, who thinks I am a chemical engineer, and the personal knowledge that I am one because I do chemical engineering work, as defined in the various chemical engineering texts.

Paradoxically, my A.I.Ch.E. membership is the only factor which tends to lower me professionally. The lessening of my professional standing is obviously not the intent of the Institute. Consequently, an immediate change in the classification system is desirable.

Regardless of the validity of the above argument, the Institute should in the near future at least define the term "responsible position" and the term chemical engineer. If a chemical engineer does not necessarily have to occupy a "responsible position," in order to be classified as such, then logically the "responsible position" clause should be eliminated as a requirement for full membership in the Institute.

QUESTIONNAIRE

Massachusetts—A.I.Ch.E. should ask colleges to stress personal relations.

Massachusetts—Too much domination by professors and management. Need society by and for engineers.

Massachusetts—A.I.Ch.E. should attract sanitary engineers who now are split up among other societies.

Missouri—Institute should have subdivisions like ACS and each should have its own publication.✳

Maryland—Initiate an "activities award" plan to stimulate members in serving the Institute in various activities.

Missouri—The A.I.Ch.E. is an excellent organization, its aims and accomplishments are wonderful.

New York—My opinion of the A.I. Ch.E. is of the highest. Institute has done much to advance the standards of the profession and have made many worthwhile contributions. It is the most worthwhile of professional societies with which I have had association.

New York—Is it possible that management viewpoint, which certainly represents a minority of the membership, is disproportionately represented and responsible for formulating Institute policy?

New York—If privately endowed and operated universities are to survive (and they must!), they must get closer to the needs of "free enterprise" industry. By studying and then developing the type of curricula best suited to industry's needs, a closer working relationship is sure to develop and substantial funds to support privately endowed universities would be forthcoming.

California—The issuance of the questionnaire is a step in the right direction. (Increasing individual's participation in the affairs of the Institute), and those responsible are to be commended.

Delaware—The questionnaire should have inquired into extracurricular activities.

Kansas—In your next questionnaire why not find out what are reading habits of the membership?

Iowa—Questionnaire a fine idea. Could be profitably used by a local section. Hope results will be published.

California—Employment Clearing Houses are felt to be an important needed Institute activity. These should cover all levels of interest and experience.

Ohio—Set up employment clearing house.

Kansas—I would like to see A.I.Ch.E. do more towards aiding a member in obtaining satisfactory employment. Difficult to learn much about company until after he goes to work and then it is too late. Perhaps a rating system could be worked out for various companies.

Illinois—A simple informal employment exchange at meetings should be a useful addition.

✳ See footnote 16.

NEWS

M.I.T. STUDENTS ELECT CHEMICAL ENGINEERING

Chemical engineering was the second most popular choice of students entering Massachusetts Institute of Technology this fall. One hundred and twenty-eight freshmen elected the chemical engineering curriculum, compared with 187 enrolling in electrical engineering, the first choice, and 122 in mechanical engineering, the third choice.

The total registration of the entering class this year is 843, nearly 100 fewer than in 1952. The tentative registration figure of 1,924 graduate students however marks a new high in the school's history, according to Joseph C. MacKinnon, registrar.

UNDERGRADUATE GRANTS IN ENGINEERING

Senior-year technical scholarships in chemical, mechanical, and metallurgical engineering have been established at forty-one engineering colleges and universities by Union Carbide and Carbon Corp., as recently announced by Morse G. Dial, president. Selection of the recipients will be made by the universities and will be based on the student's past performance and his potential for engineering and scientific study and for successful employment in industry. A specific purpose of the program is to increase the number of technical graduates trained in various scientific fields. The scholarships will cover full tuition for the senior year and $200 for necessary books and fees.

Divisions of Union Carbide sponsoring the scholarships are Bakelite Co., Carbide and Carbon Chemicals Co., Electro Metallurgical Co., Haynes Stellite Co., Linde Air Products Co., National Carbon Co., and U. S. Vanadium Co.

ATOMIC FORUM GETS MANAGERIAL STAFF

Appointment of two new officers of the Atomic Industrial Forum, Inc., was announced recently by Walker L. Cisler, president. Charles E. Robbins, formerly vice-president of Bozell & Jacobs, Inc., and Oliver Townsend, formerly assistant to the chairman of the A.E.C., were respectively made executive manager and assistant executive manager and secretary of the Forum, an association of businessmen, engineers, scientists, and educators incorporated last April to foster the development and utilization of atomic energy for peaceful purposes. Headquarters of the Forum are at 260 Madison Ave., New York 16.

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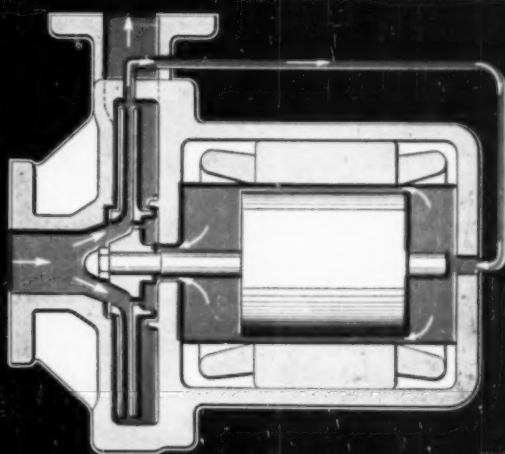
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MARGINAL NOTES

Colorless But Sweet

Glycerol. Carl S. Miner and N. N. Dalton, Editors, A.C.S. Monograph No. 117. Reinhold Publishing Corp., New York (1953), 460 pp. $12.00.

Reviewed by F. G. Perry, Jr., Arthur D. Little, Inc., Cambridge, Mass.

This book will probably find its widest use among chemists, purchasing agents, and the like, who are immediately concerned with purchase of glycerol, its specifications, methods of analysis, etc., and among only those engineers who are directly concerned with recovery or processing of glycerol.

The coverage of the subject is complete, with the exception that economic considerations of interest to chemical engineers, such as operating and investment costs and economic comparisons among sources or processes are not discussed. The book is logically organized, starting with history and economics (economics in this case involves superficial market and price information), then proceeding rather laboriously through natural sources, production, recovery and refining, specifications, analyses and properties, to the last twenty-six pages devoted to uses.

About one quarter of the book discusses methods of production and refining, in which excessive emphasis is given to soap manufacture and the attendant recovery and refining of glycerol, in contrast with only four pages devoted to the production of synthetic glycerol from propylene, failing to point out the increasing importance of synthetic glycerol and the declining production of glycerol from soap manufacture and fat splitting. The sections devoted to soap manufacture and related operations could easily have been shortened and excessive discussion is devoted to such things as an elementary lesson in physical chemistry, the operating principles of a multitude effect evaporator, and the mechanical details of a Bird continuous solid bowl centrifuge, making the reader wonder at times just what the subject matter is that he is reading about.

Sections covering standards and specifications, analyses, physical and chemical properties and derivatives of glycerol constitute more than 50 per cent of the volume and are valuable as a reference for chemists and engineers engaged in production and utilization of glycerol. These chapters, for the most part, contain reproductions from various sources of complete specifications, analytical procedures, tables and plots of physical and chemical data—all of which are available in the literature. Two rather interesting chapters, although limited in their application, cover the biochemical use of glycerol and physiological action of glycerol. The last chapter on uses of glycerine covers generally the miscellaneous fields and products in which this important raw material is consumed. The index appears complete and sufficient cross-references are given to allow easy location of all information.

Materials—Simple and Complex

Textbook of Engineering Materials. Melvin Nord. John Wiley & Sons, Inc., New York (1953), 548 pp. $6.50.

Reviewed by James Coull, Professor and Head, Chemical Engineering Department, University of Pittsburgh, Pittsburgh, Pa.

Relatively few books have been published in recent years on the subject of engineering materials. The accumulation of information in this field is usually studied in trade journals, manufacturers' catalogs, and sales circulars. Marketing interest has developed to the point where it is difficult, even for the layman, to be unaware of the special uses and singular properties of this or that product. The engineer should be able to evaluate claims made by competing manufacturers, hence the need for a sound knowledge of engineering materials.

Professor Nord advances a text aimed at the advanced freshman or beginning sophomore level for all engineers. Ably written and clearly illustrated throughout, the text is well within the comprehension of any student who has successfully completed a modern course in high school chemistry.

The book is divided into four main parts as follows:

I. A study of principal sources and types of raw materials, including formation of deposits, their distribution and removal (Brief but well organized).

II. Production of engineering materials, including mineral dressing, unit chemical processes in the production of engineering materials as well as the principles and processes of extractive metallurgy (Treatment brief and qualitative).

III. Properties of engineering materials, beginning with simple ideas on the states of matter and carrying the reader through an elementary analysis of alloy diagrams. This is followed by a chapter on the mechanical properties of engineering materials and the section ends with a chapter on physical and chemical properties (Organization of material excellent for elementary reader).

IV. Specific Engineering Materials is organized in five sections comprising: materials for the generation of energy, metals, natural and artificial stone, natural and synthetic organic materials of construction, and protective materials. Part IV comprises almost two thirds of the text and provides a sound sequel in the application of principles, described in the previous three parts, to a well-selected list of specific engineering materials. These include water, fuels, explosives, ferrous metals, nonferrous metals, etc. Statistics relating to production and occurrence find frequent reference throughout the text and in the bibliographic references at the end of each chapter.

This book might with advantage be adopted as a required reading assignment for engineering students beginning their sophomore year.

Distillation Literature. Index and Abstracts 1946-1952 Inclusive. Arthur and Elizabeth Rose. Applied Science Laboratories, Inc., State College, Pa. (1953), $25.00.

A highly efficient type of bibliography containing abstracts of all the literature in the distillation field arranged by subject. Includes abstracts of journal papers, meeting papers, patents, books, book reviews, important advertising announcements, news items. All abstracts on each subject are gathered together on adjacent pages. There are about 600 pages, 5,000 abstracts, and 12,000 index entries. A complete author index, and a list of subject index headings are included.

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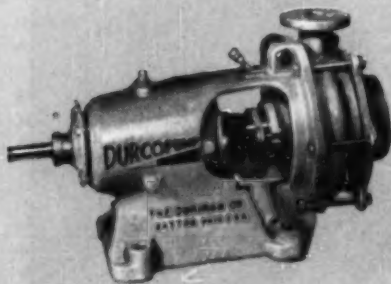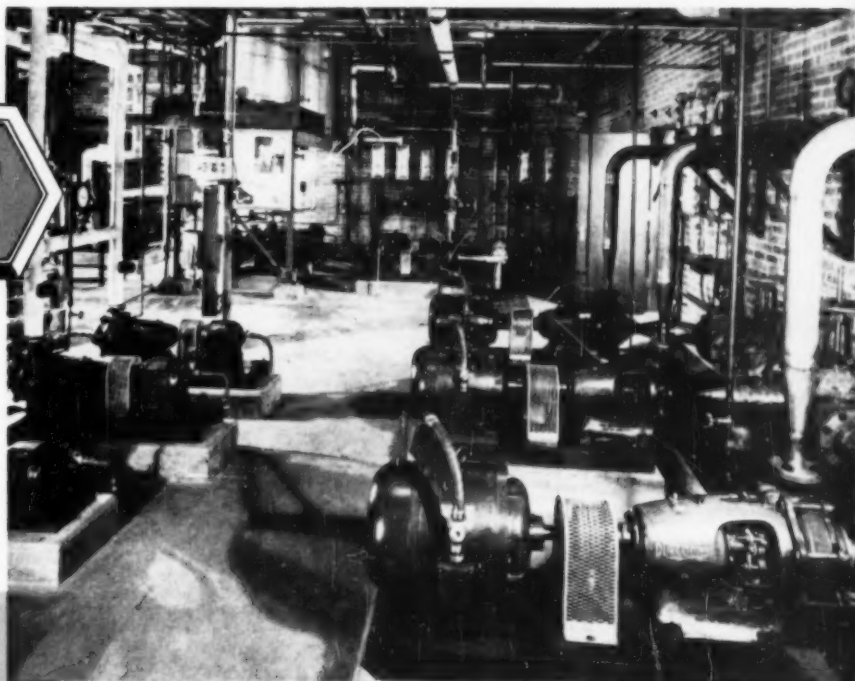
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CANDIDATES FOR MEMBER-SHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before January 15, 1954, at the Office of the Secretary, A.I.Ch.E., 120 East 41st Street, New York 17, N. Y.

Applicants for Active Membership

Beno, Peter P., Buffalo, N. Y.
Bonham, Frank S., Long Beach, Calif.
Falk, Carl F., Richland, Wash.
Gertz, Melvin H., Dallas, Tex.
Hanmer, Robert S., Borger, Tex.
High, Donald A., Dayton, Ohio
Highlands, Matthew E., Orono, Maine
Jackson, Melbourne L., China Lake, Calif.
Jong, James J., Los Angeles, Calif.
Johnson, Walter F., So. Plainfield, N. J.
Korpi, Edwin O., Cincinnati, Ohio
Loew, Edward J., Wilmette, Ill.
Macy, Philip A., Jr., E. Alton, Ill.
Marcot, Guy C., Piney River, Va.

Mazza, Harold, Trona, Calif.
Meason, G. H., Baytown, Tex.
Olsen, John Lee, Marcus Hook, Pa.
Peckham, Herbert H., New Castle, Del.
Pollock, Lyle W., Bartlesville, Okla.
Rylands, Robert N., Cuyahoga Falls, Ohio
Schwartz, Milton S., Philadelphia, Pa.
Schweppe, Joseph L., Pasadena, Calif.
Scott, William C., Jr., Florence, Ala.
Sklar, George, Charleston, W. Va.
Smith, Charles T., Lombard, Ill.
Spencer, Max R., Decatur, Ind.
Stanley, Maurice E., Port Arthur, Tex.
Steioff, A. F., Cincinnati, Ohio
Trethewey, Graham D., Woodfibre, B. C., Canada
West, Herbert M., South Charleston, W. Va.

Wirges, M. F., Bartlesville, Okla.
Woodworth, Parke, Grosse Pointe, Mich.

Applicants for Associate Membership

Klein, Donald C., El Paso, Tex.
Kloosterman, Ate H., New York, N. Y.
Pierce, J. Louis, Greenville, S. C.

Applicants for Junior Membership

Almon, Charles C., Texas City, Tex.
Ballo, H. John, Antioch, Calif.
Bartlett, M. C., Jr., Pine Bluff, Ark.
Biles, William R., State College, Pa.
Bonnell, Allan H., Westfield, N. J.
Brown, Larry R., Blacksburg, Va.
Buttimer, John F., Glen Burnie, Md.
Carman, James M., Alexandria, Ky.
Copeland, Robert H., Waynesboro, Va.
Covey, William E., Army Chemical Center, Md.
Fehskens, Eugene, Bronx, N. Y.
Galluzzo, Joseph F., Pittsburgh, Pa.
Gerson, Herbert, Bronx, N. Y.
Haggin, Joseph H. S., Milwaukee, Wis.
Hatzell, John J., Philadelphia, Pa.
Henry, Paul J., Akron, Ohio
Hodges, Harold E., Louisville, Ky.
Holmes, Walter L., Houston, Tex.
James, Frank E., Jr., Texas City, Tex.
Lee, John Maxim, Wilmington, Del.
Leonard, Edward F., Willow Grove, Pa.
Mandil, M. Amin, Berkeley, Calif.
Marr, Clyde M., Willoughby, Ohio
McEwan, Gilbert J., St. Louis, Mo.
McMakin, L. E., Jr., Houston, Tex.
McMicking, James H., Detroit, Mich.
Melancon, John W., Baton Rouge, La.
Mendelson, Harvey, New York City, N. Y.
Miller, Alfred M., Jr., Beaumont, Tex.
Muller, Karl A., Jr., Texas City, Tex.
Nasser, John, Woodbury, N. J.
Nelson, George Gus, Jr., Washington, D. C.
Pokrzywnicki, Edmund C., Springfield, Mass.
Reider, C. M., Martinez, Calif.
Reisner, Peter E., Akron, Ohio
Remer, Norman A., Chicago, Ill.
Renard, Michel, Palo Alto, Calif.
Reumont, Maurice R., Washington, D. C.
Reynolds, James H., Paulsboro, N. J.
Riggs, James R., Jr., St. Paul, Minn.
Roberts, William N., Portsmouth, Va.
Rockstroh, Richard K., Chester, Pa.
Roe, Roland A., Clifton, N. J.
Shoaff, Victor C., Chicago, Ill.
Skillman, Frank M., Kinston, N. C.
Smith, Donald E., Drexel Hill, Pa.
Sondak, Norman Edward, Far Rockaway, N. Y.
Starr, A. Thomas, Belleville, Ill.
Symington, Kenneth A., Havana, Cuba
Walsh, James F., Jackson Heights, N. Y.
Williams, James L., Kingsport, Tenn.

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Secretary's Report

S. L. TYLER

The Executive Committee met at The Chemists' Club on Nov. 13, approved the Minutes of previous meetings and accepted the Treasurer's reports for the months of September and October. Secretary reported that there were no adverse comments on the applicants for membership whose names appeared in the October issue of C.E.P. and therefore they were declared elected to the grades of membership indicated. The following counselors were appointed for the student chapters at the colleges as indicated:

University of Denver—J. M. Lenoir
University of Idaho—M. L. Jackson
State University of Iowa—J. O. Osburn
University of Maryland—W. J. Huff
Massachusetts Institute of Technology—A. S. Michaels
Montana State College—H. A. Saner
Northwestern University—W. F. Stevens
University of Oklahoma—R. L. Huntington
Oregon State College—J. G. Knudsen
University of Southern California—J. H. Ballard
University of Washington—A. L. Babb

Four resignations from Junior membership were received and accepted.

N. R. Grant, G. A. Coulman, and G. S. Cochrane were placed on the Suspense List because of their having entered the Armed Forces. R. C. Brock was removed from the Suspense List, having completed his tour of duty.

The budgets of both the Institute and C. E. P. were presented and discussed thoroughly and approved with the recommendation that they be acted upon favorably by the Council.

The Council met at The Chemists' Club on Nov. 13 with fifteen of the seventeen members of Council present. Minutes of previous meetings were approved.

Recommendations of the chairmen of standing committees of the Institute were presented and with only minor modifications approved. Representatives of the Institute with other groups were also appointed.

Upon the recommendation of the Program Committee, Council approved the holding of a meeting of the Institute in Los Angeles, Calif. in March, 1956.

The Council also voted to recognize to as great an extent as possible the Bicentennial of Columbia University at the time of the annual meeting in New York City in December, 1954.

Recommendations of the Constitution and By-Laws Committee in line with discussions at previous meetings of Council were presented and discussed at some length. These amendments concerned membership matters as well as election procedures. Modifications were made and referred back to the Constitution and By-Laws Committee with the request to submit a new draft of proposed modifications at the December meeting of Council.

The Research Committee, through its chairman, W. E. Lobo, presented a proposed form of contract to be used in connection with research assignments by that Committee with the universities at which special research work is carried on. This contract was approved.

Engineers Joint Council had requested the participating societies to send a special questionnaire to their members in order to obtain information regarding employment conditions particularly with regard to unionization, collective bargaining, and professional license. The mailing was approved.

The report of the Tellers Committee on the Election Ballot was presented and accepted by the Council and the following were declared elected:

President ..... Chalmer G. Kirkbride
Vice-President ... Barnett F. Dodge
Treasurer ... George Granger Brown
Secretary .... Stephen L. Tyler
Directors for a three-year term beginning Jan. 1, 1954:
          Loren P. Scoville
          Ray P. Dinsmore
          George E. Holbrook
          W. L. Faith

REVIEW OF A.S.T.M. RESEARCH AVAILABLE

Reprints of the "Review of A.S.T.M. Research," compiled from A.S.T.M. Bulletins, are available, the society has announced. The review lists the work of the various technical committees of the society on such materials as metals, cement, mortars, clay pipe, lime, refractories, concrete, gypsum, thermal insulating materials, acoustical materials, ceramic whiteware, paints and varnishes, petroleum products, wood, paper, coal and coke, rubber, soaps, aromatic hydrocarbons, and others. Copies may be obtained without charge from the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

LOCAL SECTION

C. G. Kirkbride, President-elect of A.I.Ch.E. and banquet speaker at the Eighth Annual Technical Meeting, South Texas Section, held at the Galvez Hotel, Galveston, Tex., talks about the present status of, and future planning for, the A.I.Ch.E. The registration figure at the meeting was 564 and attendance at the banquet was 322.

H. J. Bowen, president of Industrial Models, Inc. of Wilmington, Del., gave an illustrated talk on "Who Uses Industrial Engineering Models and Why" to 77 members of the St. Louis Section, at a dinner meeting Nov. 17, 1953 at the Forest Park Hotel. He said that principal users of models are chemical processing plants, petroleum refineries, steam power plants, and automobile and airplane assembly plants.

At the Oct. 20 meeting of the Section, 82 members and guests heard Alvan H. Tenney, product manager, Fine Chemicals Division, Carbide & Carbon Chemicals Co., talk on his company's $13 million pilot plant for production of chemicals through hydrogenation of coal at Institute, W. Va.

Richard G. Kerlin added another note to his story on St. Louis Section activities: Seminars led by chemical engineers in industry would continue this year at Washington University.

The November meeting of the Southern California Section was held at Scully's Restaurant in Los Angeles, and featured Harry Pearlman, project engineer in the atomic energy department of North American Aircraft, who talked on "Nuclear Reactors for Research Power."

Results of the election of new officers to serve for the year 1954 are as follows:

Chairman .... Arnold M. Ames
Vice-Chairman .... Stephen G. Sevougian
Secretary .... Blaine B. Kuist
Treasurer .... Phil M. Huemmer
Executive Council
  Senior Member .... Roger W. Hoffman
  Junior Member .... J. W. Jensen
Delegate to Los Angeles Engineering
  Council .... George R. Lake

FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee

Loren P. Scoville, Jefferson Chemical Company, Inc.   260 Madison Ave., New York 16, N. Y.

MEETINGS

Washington, D. C., Statler Hotel, March 7-10, 1954.
TECHNICAL PROGRAM CHAIRMAN: George Armistead, Jr., Consult. Chem. Eng., George Armistead & Co., 1200 18th St. N.W., Washington 6, D. C.

Springfield, Mass., Hotel Kimball, May 16-19, 1954.
TECHNICAL PROGRAM CHAIRMAN: E. B. Fitch, Asst. to Res. Dir., The Dorr Co., Westport, Conn.

Ann Arbor, Mich., Univ. of Mich., Ann Arbor, Mich., June 20-25, 1954—Conference on Nuclear Engineering.
TECHNICAL PROGRAM CHAIRMAN: D. L. Katz, Chairman, Dept. of Chem. and Met. Eng., Univ. of Mich., 2028 E. Eng. Bldg., Ann Arbor, Mich.

Glenwood Springs, Colo., Hotel Colorado, Sept. 12-15, 1954.
TECHNICAL PROGRAM CHAIRMAN: Dr. Charles H. Prien, Head, Chem. Div., Denver Res. Inst., Univ. of Denver, Denver 10, Colo.

Annual—New York, N. Y., Statler Hotel, Dec. 12-15, 1954.
TECHNICAL PROGRAM CHAIRMAN: G. T.

Skaperdas, Assoc. Dir., Chem. Eng. Dept., M. W. Kellogg Co., 225 Broadway, N. Y. 7, N. Y.
ASST. CHAIRMAN: N. Morash, Titanium Div., National Lead Co., P. O. Box 58, South Amboy, N. J.

Louisville, Ky., Kentucky Hotel, March 20-23, 1955.
TECHNICAL PROGRAM CHAIRMAN: R. M. Reed, Tech. Dir., Gas Proc. Div., The Girdler Corp., Louisville 1, Ky.

Houston, Texas, Shamrock Hotel, May 1-4, 1955.
TECHNICAL PROGRAM CHAIRMAN: J. L. Franklin, Res. Assoc., Humble Oil & Refining Co., P. O. Box 1111, Baytown, Texas.

Lake Placid, N. Y., Lake Placid Club, Sept. 25-28, 1955.
TECHNICAL PROGRAM CHAIRMAN: L. J. Coulthurst, Chief Proc. Designer, Foster Wheeler Corp., 165 Broadway, New York 6, N. Y.

Annual—Detroit, Mich.—Statler Hotel, Nov. 27-30, 1955.
TECHNICAL PROGRAM CHAIRMAN: T. J. Carron, Head, Chemical Tech. Office, Ethyl Corp., Res. Labs., 1600 West Eight Mile Road, Detroit 20, Mich.

SYMPOSIA

SYMPOSIA FOR WASHINGTON MEETING

Mixing

Patents

Chemical Engineering in the Fertilizer Industry

Liquid Entrainment and Its Control

Chemical Engineering Fundamentals

New Metal Technology

Use of Computers in Chemical Engineering

Polymeric Materials of Construction
CHAIRMAN: C. C. Winding, Assist. Dir., College of Eng., Cornell Univ., Ithaca, New York.
MEETING—Springfield, Mass.

Process Design
CHAIRMAN: W. W. Kraft, The Lummus Co., 385 Madison Ave., New York 17, N. Y.
MEETING—Springfield, Mass.

Nuclear Engineering
CHAIRMAN: D. L. Katz, Chairman (Address: See Ann Arbor Meeting).
MEETING—Ann Arbor, Mich.

Agglomeration
CHAIRMAN: A. P. Weber, International Engineering, Inc., 15 Park Row, New York, N. Y.
MEETING—Glenwood Springs, Colo.

Reaction Kinetics
CHAIRMAN: N. R. Amundson, Dept. of Chem. Eng., Univ. of Minnesota, Minneapolis 14, Minn.
MEETING—New York, N. Y,

Gas Absorption
CHAIRMAN: R. L. Pigford, Div. of Chem. Eng., Univ. of Delaware, Newark, Del.
MEETING—New York, N. Y.

Solvent Extraction
CHAIRMAN: Dr. R. B. Beckmann, Dept. Chem. Eng., Carnegie Inst. of Tech., Schenley Park, Pittsburgh 13, Pa.
MEETING—New York, N. Y.

Heat Transfer
CHAIRMAN: R. L. Pigford, Div. of Chem. Eng., Univ. of Delaware, Newark, Del.
MEETING—Louisville, Ky.

Centrifugation
CHAIRMAN: J. O. Maloney, Chairman, Dept. Chem. Eng., Univ. of Kansas, Lawrence, Kan.

Nucleation Processes
CHAIRMAN: E. L. Piret, Dept. Chem. Eng., Univ. of Minn., Minneapolis 14, Minn.

Submitting Papers

Members and nonmembers of the A.I.Ch.E. who wish to present papers at scheduled meetings of the Institute should follow the following procedure.

First, write to the Secretary of the A.I.Ch.E., Mr. S. L. Tyler, American Institute of Chemical Engineers, 120 East 41st Street, New York, requesting three copies of the form "Proposal to Present a Paper Before the American Institute of Chemical Engineers." Complete these forms and send one copy to the Technical Program Chairman of the meeting for which the paper is intended, one copy to the Chairman of the A.I. Ch.E., Program Committee, address at the top of this page, and one copy to the Editor of Chemical Engineering Progress, Mr. F. J. Van Antwerpen, 120 East 41st Street, New York.

If you wish to present the paper at a particular symposium, one copy of the form should go to the Chairman of the symposium instead of the Technical Program Chairman of the meeting.

Before Writing the Paper

Before beginning to write your paper you should obtain from the meeting Chairman, or from the office of the Secretary of the A.I.Ch.E., at 120 East 41st St., New York, a copy of the A.I.Ch.E. Guide to Authors, and Guide to Speakers. These cover the essentials required for submission of papers to the A.I. Ch.E. or its magazines.

Copies of Manuscript

Five copies of each manuscript must be prepared. For meetings, one should be sent to the Chairman of the symposium, and one to the Technical Program Chairman of the meeting at which the symposium is scheduled. If no symposium is involved, the two copies should be sent to the Technical Program Chairman. The other copies should be sent to the Editor's office since manuscripts are automatically considered for publication in Chemical Engineering Progress, or the symposium series of Chemical Engineering Progress, but presentation at a meeting is no guarantee that they will be accepted.

DEADLINE DATES FOR PAPERS

SPRINGFIELD MEETING—January 9, 1954
ANN ARBOR MEETING—February 15, 1954
GLENWOOD SPRINGS MEETING—May 12, 1954
NEW YORK MEETING—August 12, 1954
LOUISVILLE MEETING—November 20, 1954
HOUSTON MEETING—definite dates have not been set.
LAKE PLACID MEETING—May 25, 1955
DETROIT MEETING—July 27, 1955

MARGINAL NOTES

Reactions Classified in Guide Book

Synthetic Methods of Organic Chemistry, Vol. 7. W. Theilheimer; Interscience Publishers, Inc., New York (1953), XI + 450 pp. $14.90.

Reviewed by J. E. Snow, Heyden Chemical Corp., Garfield, N. J.

This is the seventh volume of this work which has now become an annual publication. In this book the author has collected abstracts of the new and extraordinary preparations and methods appearing in the chemical literature during the course of a year. He uses an abundance of formulae to illustrate the reactions given and lists raw materials, references and yields clearly. For purposes of reaction classification he has employed a system which, while not difficult to master, should be well understood in order to derive the greatest value from the book. A compound index is included to aid in locating material for those not versed in the classification method.

Volume 7 contains 919 abstracts under 176 different classification headings covering a wide variety of chemical transformations. Most of these entries are from readily available journals. The more obscure and foreign journals are only abstracted when the same-type information is not contained elsewhere. This volume does not replace "Chemical Abstracts" or primary literature references, but merely acts as a guide for screening methods for possible application to a problem.

This series is primarily for the laboratory research chemist. Here he might find the more unusual and specific type of reaction which would solve a preparative problem not yielding to conventional methods. The material in this volume would, by its very nature, be of limited value to the average chemical engineer engaged in development and production.

Heat Transfer

A Symposium. University of Michigan Press, Ann Arbor, Mich. (1953), 286 pp. $5.00.

Reviewed by Edgar L. Piret, Professor of Chemical Engineering, University of Minnesota, Minneapolis, Minn.

This publication brings together in book form the lectures on special topics in heat transfer presented by the speakers of the University of Michigan 1952 Symposium on Heat Transfer. The emphasis is placed on the presentation and authoritative interpretation of recent developments in the specific areas covered. Hence this book can be well recommended to those who are interested in the general field of heat transfer but who have not had the opportunity to follow the numerous individual research publications. As seems to be characteristic of the product of university presses, the format and presentation are attractive.

Such publications as this one help to solve the reading problem of the researcher who knows that certain research activities are related to his own interests but who cannot possibly find the time to cover the immense body of research literature emanating nowadays in the technical and scientific press.

The chapters listed are:

1. Conditions in Heat Transfer Problems which Create High Thermal Stress—Alan S. Foust.
2. Behavior of Materials under conditions of Thermal Stress—S. S. Manson.
3. Liquid-Metal Heat Transfer—H. F. Poppendick.
4. Heat Transfer with Evaporation—Warren M. Rohsenow.
5. Recent Developments in Convective Heat Transfer with Special Reference to High-Temperature Combustion Chambers—Martin Summerfield.
6. Convective Heat Transfer at High Velocities—E. R. G. Eckert.
7. Transpiration and Film Cooling—E. R. G. Eckert.
8. Forced Convection from Nonisothermal Surfaces—Myron Tribus and John Klein.
9. Theoretical Considerations in Rarefied-Gas Dynamics—S. A. Schaaf.
10. Experimental Methods and Results in Rarefied-Gas Dynamics—S. A. Schaaf.
11. Comparison of Temperatures in Solid Bodies and Their Scaled Models—R. V. Churchill.

Books Received

Fabricated Materials & Parts—A Comparison of Cost & Design Factors. T. C. DuMond. Reinhold Publishing Corp.., New York (1953), 327 pp. $6.50.

Refractory Hard Metals. Paul Schwarzkopf and Richard Kieffer in collaboration with Werner Leszynski and Fritz Benesovsky. The MacMillan Co., New York (1953), 447 pp. $10.00.

Pipe and Tube Bending. Paul B. Schubert. Industrial Press, New York (1953), 183 pp. and 159 illustrations, $5.00.

LOCAL SECTION NEWS
(*Continued from page 61*)

Gale S. Peterson, the corresponding secretary, also sent in a detailed account of the September and October meetings.

The October meeting was a special feature (Ladies Night) which will undoubtedly become an annual institution. After a dinner and short business meeting held at the Caroline Pines Restaurant in Los Angeles, the entire group of approximately 125 members, wives and guests adjourned temporarily to reconvene at the new C. B. S. Television City in Hollywood for a conducted tour of the new multi-million building and studio facilities.

The Ichthyologists (Boston Section) got a real lesson in the development of personal salesmanship at the regular meeting on Nov. 20. Walter G. Strathern, assistant director of industrial relations, Eastern Gas & Fuel Associates, entitled his talk "How to be Human on the Job," and with "outstanding eloquence," says Reporter A. G. Smith, he delivered some real pointers on the practice of tactics and techniques in every day dealing with people.

The October meeting of the Cleveland Section began with a dinner in the Oak Room at Fenn College. The speaker for the evening was Aaron Teller. He gave a talk entitled "The Rosette, a New Packing for Diffusional Operations based on High Interstitial Holdup."

W. H. Charbonnet, who sends us news of the Cleveland Section, reports the following plan of meetings as outlined by Herb Metzger, chairman.

January, 1954
 Subject—Catalysis
 Speaker—From Harshaw Chemical
   Co.
February
 Subject—Your Life and Man-made
   Fibers
 Speaker—Edwin H. Danneberger
   Textile Fibers Dept.
   Du Pont Co.
March
 Subject—Spray Drying
 Speaker—D. A. Smith
   Swenson Evaporator Co.
   Mgr. Spray Drying Dept.
April
 Subject—Human Relations
 Speaker—B. H. Taylor
   B. F. Goodrich Co.
   Employee Relations Division
May
 Plant Trip as Guests of Diamond Alkali Co., Painesville, Ohio

The Cleveland Technical Societies Council has asked the Cleveland Section to furnish six men for the annual "Career Conference on Engineering."

LOCAL SECTION NEWS
(Continued from page 65)

The 1952-53 Board of Directors of the Rochester Section of the A.I.Ch.E. voted $100 to the University of Rochester as a scholarship fund for a worthy chemical engineering student; the student to be determined by the Scholarship Committee of the University. The 1953-54 Board of Directors has voted to continue this scholarship on an annual basis. William Eilinger, secretary, Rochester Section, states that at the first meeting, this decision was confirmed by the general membership, with the final decision and amount to be determined by the Board of Directors. The first student to be granted this scholarship is Donald P. Sullivan, a freshman at the University.

The Maryland Section held its first meeting of the 1953-54 season on Oct. 20, at the Engineers Club in Baltimore City. A cocktail party preceded the dinner. The speaker for the evening was David E. Pierce, engineer-maintenance consultant. Mr. Pierce's subject was "Cost Control by Kilowatts," in which, in the words of T. E. Byerly, publicity chairman, he explained how maintenance expenditures can be systematically and accurately forecast when based on kilowatt power consumption of a manufacturing concern.

William MacNevin, professor of chemistry at the Ohio State University, discussed "The Trapping of Solar Energy" at a meeting of the Central Ohio Section on Nov. 24. According to our reporter G. F. Sachsel, the meeting, at the Ohio State University Faculty Club, was preceded by a dinner at which C. J. Geankoplis, professor of chemical engineering at Ohio State, presided.

Oct. 12, 1953, was the date of a meeting of the New Orleans Section held jointly with the Louisiana Engineering Society at the Engineers and Architects Club of New Orleans. W. L. Badger was speaker of the evening and his talk included the history of chemical engineering. Mr. Badger served as director of research for Swenson Evaporator Co. from 1917 to 1937 and now serves as a consultant for various companies. Alton S. Hall, chairman of the Publicity Committee, sent in a report of this meeting.

A meeting of the El Dorado section was held Oct. 9, 1953. Joe Flowers, Sr., account executive, Merrill Lynch, Pierce, Fenner and Beane, spoke on the behavior of chemical stocks on the New York Stock Exchange, according to reporter White.

J. T. Hugill of the Canadian Liquid Air Co., Ltd., will address the New York Section at the Brass Rail on Jan. 20, at 6 P.M. A. Jonnard of the Publicity Committee of the section, says the subject will be "Low Temperature Techniques."

Two meetings have been held by the Northeastern New York Section this fall. H. A. Steinhauser, Jr., reported on both. The more recent, held on Nov. 5, was a trip through the General Electric Co.'s Silicone plant at Waterford, N. Y. The members had an opportunity to see the process from start to finish.

The earlier meeting was held on Oct. 13, in Watervliet at the Behr-Manning Corp. The meeting included a plant trip through the coated abrasives plant.

A meeting of the Ohio Valley Section was held on Nov. 2 at the Engineering Society of Cincinnati headquarters. Nathan Gilbert, associate professor of chemical engineering at the University of Cincinnati, talked on "Chemical Engineering at Tennessee Valley Authority." N. W. Morley, Jr., reported the meeting.

On Oct 14 the Chicago Section held its first meeting of the fall season in the Builders' Club in downtown Chicago. After dinner, R. G. Edmonds of the Carbide and Carbon Chemicals Co. presented a talk on its production of chemicals from coal in the 300 tons/day pilot plant located at Institute, W. Va. The talk was well received by the approximately 175 members and guests, so says Harry Betzig, reporter.

B. Lyle Lex, publicity chairman of Columbia Valley Section, sends in word that his section joined the Richland Section of A.C.S. on Nov. 13 in sponsoring an address by Farrington Daniels titled "Our Future Sources of Energy." He further states that on Oct. 6 and 7 the section sponsored the 1953 Chemical Engineering Industrial Show of chemical processing equipment and chemical products. The show was held in the Richland Community House. Plans are under consideration for enlarging the scope of the show and presenting it on an annual or biannual basis.

The Atlanta Section held its fourth meeting of 1953 on Nov. in Brittain Dining Hall on the Georgia Tech campus. Fifty-six members and guests attended. After a brief business session J. W. Mason, dean of engineering of Georgia Tech, spoke to the group. Dean Mason based his discussion on his "Year with Du Pont" as a participant in the Du Pont Educator in Industry Program. The talk was followed by a question-and-answer period which capped off one of the best meetings, in the opinion of the reporter, H. H. Sineath.

At the November meeting of the Texas Panhandle Section John P. Gille of Brown Instrument Division, Minneapolis-Honeywell Regulator Co. spoke on "Instrumentation for the Process Industries." Carl Kron sent in the names of the officers elected for 1954. They are:

Chairman ....Howard Weaver
Vice-Chairman ......E. H. Gray
Secretary ....T. S. Whitsel
Treasurer ....W. B. Polk
Directors: S. A. Blundell, C. M. Kron, and L. A. Webber

At the October meeting, N. V. V. Franchot of the Christy Firebrick Co. spoke on "Super Refractories."

W. E. Osborn, corresponding secretary, Phila.-Wilmington Section, informs us that the Section plans a season of ten regular scheduled meetings. This is made up of two joint meetings held in a central location (first and last meeting of the season), four meetings in the Wilmington area (second Tuesdays in November, January, February, and March), and four meetings in the Philadelphia area (third Tuesdays of the same months).

The first meeting of the current season was a joint meeting of the Philadelphia and Wilmington groups and was held in Chester, Pa. About 70 persons were present for dinner with about 110 in attendance for the meeting itself. The speaker for the evening was John R. Menke, president of Nuclear Development Associates, Inc. His talk dealt with present trends in nuclear reactors with special emphasis placed on their use for power production.

The secretary of the Terre Haute Section, B. L. Lubin, wants us to pick up all the loose ends and report on his section's doings for the past several months. (Space won't permit so extended an account—Ed.) At the meeting on Oct. 22 Sam Rudder of the Foxboro Co. discussed the outstanding improvements in the field of instrumentation, using many slides in his presentation. The section has decided to hold more meetings that are nontechnical in nature. A program of social periods, hobby groups, and other means of entertainment will be encouraged.

The second dinner meeting of the Pittsburgh Section for the 1953-54 season was held at the Sheraton Hotel on Nov. 4, 1953. Messrs. Morrissey and Black wrote us about the talk given by R. C. Werner, project supervisor, Mine Safety Appliances Co. His subject was "Sodium and Other Alkali Liquid Metals as Heat Transfer Media."

Tables and graphs were presented by Dr. Werner to illustrate such physical properties as density, viscosity, thermal conductivity, and heat capacity. Metering and processing equipment was discussed with emphasis on methods of pumping, measuring flow rates, and care that must be exercised in the design stage to avoid corrosion or other hazards. Dr. Werner stated further that applications of these metals to heat transfer are limited at present. Also that the government is operating two atomic power plants, using liquid metals to transfer heat from an atomic pile to generate steam.

PEOPLE

G. H. SCHAFER NOW AT TRONA (CALIF.) LAB.

As a part of the current program to enlarge and strengthen the research department, Glen H. Schafer joined the Trona, Calif., laboratory of the American Potash & Chemical Corp. on Oct. 29. For the present he has been assigned to work in the new products division.

Mr. Schafer obtained both the B.S. and M.S. degrees in chemical engineering at the University of Colorado. During the ensuing fifteen years he has been associated, successively, with the Magnolia Petroleum Co., U. S. Patent Office, Armour Research Foundation, and the Chas. A. Krause Milling Co. At the latter company he supervised the control laboratory and, later, was in charge of research and development.

T. S. Leary is now chief chemist of the chemicals department, Calco Chemical Division, American Cyanamid Co., Bound Brook, N. J. Prior to this assignment he held positions at Calco in the chemical engineering department, the central pilot plant, and the textile resin department. Before joining American Cyanamid, r. Leary received his B.Ch.E. and M.S. degrees from Rensselaer Polytechnic Institute, and his Ph.D. from Iowa State College.

C. Jack Thomas is now manager of the Doe Run, Ky., plant of the Mathieson Chemical Corp. Prior to this appointment he was assistant manager of Doe Run operations and prior to that superintendent of the glycol plant there. Joining the company in 1950, he participated in the engineering, construction, and start-up of the plant. Before going to Mathieson he was associated with the Dow Chemical Co. at Freeport, Tex., and Midland, Mich. Mr. Thomas did graduate work in chemistry at the University of Texas.

Russell L. Bauer is now section manager in the organic chemicals division development department of Monsanto Chemical Co., St. Louis, Mo. In this capacity he will be concerned primarily with the economic appraisal of development projects. He joined the company in 1937, after receiving his B.S. degree in chemical engineering from Washington University. Later he was employed by the W. G. Shelton Co., and in 1941 he joined the DuPont Co., returning to Monsanto in 1945 as a member of the general development department. He has been manager of the process section of the general engineering department since 1948.

John H. Wishnick, formerly superintendent of the Witco Chemical Co., Chicago, has been appointed vice-president in charge of production and transferred to Witco's headquarters in New York. Prior to his affiliations with Witco, Mr. Wishnick was, for two years, manager of the oil black division, Continental Carbon Co. at Westlake, La. He received his B.S. degree in petroleum engineering from the University of Oklahoma.

Fred L. Hartley was recently appointed manager of a new commercial development division established by Union Oil Co. in its research and process department. Mr. Hartley has been with Union Oil for fifteen years as manufacturing process supervisor in charge of process design, and for the last three years as general superintendent of operations at Union's Los Angeles refinery.

Robert E. Maier has recently become senior research supervisor in the research division, polychemicals department, Experimental Station, Du Pont Co., Wilmington, Del. In his new position he will direct development of new processes for making plastics and application of mathematical methods to solution of chemical engineering problems. Joining DuPont in 1939 at the plastics laboratory, Arlington, N. J., as a chemical engineer, he was advanced to research supervisor in 1950 when the plastics research group was moved to the Experimental Station. He received the degree of chemical engineer from the University of Cincinnati.

Wayne W. Binger is now assistant chief of the chemical metallurgy division, Aluminum Research Laboratories of Alcoa. He received his B.S. degree in chemical engineering from the University of Wisconsin in 1943.

J. W. BODMAN RETIRES

John W. Bodman, technical adviser to the Lever board of directors and director of research for twenty-five years for Lever Brothers Co., retired Nov. 1. He joined the company in 1925 after extensive experience in both research and production in the soap and edible fields. After joining Lever he contributed many new methods, patents, and processes that are still used in the industry. Mr. Bodman was graduated from the University of Missouri in 1910 with a B.S. degree in chemical engineering and was associated with Peet Brothers, The N. K. Fairbanks Co., and the Wm. Garrigue Co. in various engineering and research capacities before joining Lever.

John V. Roach has recently been made superintendent at the Chicago plant of the Witco Chemical Co. Assistant superintendent at Chicago since 1952, Mr. Roach joined Witco in 1948 as a chemical engineer. Prior to that time he was affiliated with the Grasselli Chemicals Division, DuPont Co., Cleveland, Ohio. He received his B.S. in chemical engineering from Illinois Institute of Technology.

Herbert C. Thober, chief chemical engineer for the Sun Oil Co., Toledo, Ohio, was elected president of the Toledo Society of Chemical Engineers for the year 1954. The Society, which is the representative group for chemical engineers from all of Toledo's industries, also voted to assist the University of Toledo in the training of chemical engineering students for industries in which they are most needed. At the same time Lawrence Larsen also of Sun Oil, was named secretary-treasurer, and William Williams, Maumee Development Co., was elected to the executive committee.

J. Robert Snyder, a graduate student in the department of chemical engineering at the University of Pennsylvania, has received a research fellowship provided by Autoclave Engineers, Inc. He is engaged in a fundamental study of agitation as a factor in chemical reactions.

The appointment of Emil Hladky as assistant chief chemical engineer, Calco chemical division, American Cyanamid Co., Bound Brook, N. J., has been announced. Prior to this appointment he was with the company's ultramarine plant of Newark, N. J., and previously held the positions of chief engineer and assistant manager of the titanium dioxide department at the Piney River plant, Va.

Louis E. Garono was recently appointed chief engineer of the Chemical Corps Engineering Agency, Army Chemical Center, Md. Mr. Garono, who received his M.S. and B.S. degrees in chemical engineering from the Massachusetts Institute of Technology, was formerly chief of the plants division, Engineering Agency, Army Chemical Center, Md., as well as engineering superintendent of the Atlantic Gelatin Division of General Foods Corp.

The appointment of Fred Wehmer as technical sales manager has been announced by Rubber & Asbestos Corp., Bloomfield, N. J. Mr. Wehmer was formerly technical director of the adhesives and coating division of Minnesota Mining & Manufacturing Co.

CLASSIFIED SECTION

SITUATIONS OPEN

PROCESS DEVELOPMENT

Physical Chemists for process development in Atomic Energy feed materials production and refining.

B.S. and M.S. degrees required. Experience desired but not necessary.

Reply to Box 2-12, stating qualifications and salary requirements.

CHEMICAL ENGINEERS
METALLURGICAL ENGINEERS

Permanent position open in most rapidly growing aluminum smelter in the United States. Excellent opportunity for rapid advancement. Write Alloys & Chemicals Mfg. Co., Inc., 4365 Bradley Road, Cleveland 9, Ohio.

PROJECT ENGINEERS

New York Engineering and Construction firm. Long established in the design and construction of process plants for the petroleum refining and chemical industries; has several openings in their project engineering dept. for graduate Chemical, Mechanical or Civil Engineers, with about 2-5 years experience in related plant operations, or design.

In reply please submit in detail educational background and experience.

Box 1-12

CHEMICAL ENGINEER

Recent graduate, with Ph.D. degree or equivalent preferred, for fundamental engineering research on a variety of chemical engineering projects. Excellent opportunity for interesting and original work with large chemical company in Midwest. Salary commensurate with training and experience. Please give complete résumé of education and personal history. Inquiries also invited from present Ph.D. candidates. Box 6-12.

CHEMICAL ENGINEER—Young man, 25 to 30, two to four years' experience, rubber compounding and plastics extrusion. Excellent future. Progressive Northeastern Ohio manufacturer. Box 7-12.

DEVELOPMENT CHEMICAL ENGINEERS—Leading producer of heavy chemicals has openings in the development department for chemical engineers to perform chemical engineering calculations, process and equipment design, and pilot plant operation. Development facilities located in pleasant community in Westchester County, N. Y., offering desirable living conditions. Excellent opportunity for graduate engineers with 0 to 4 years' experience (preferably in the heavy chemical or petroleum industries). Please include a résumé and state scholastic standing and salary requirements. Box 8-12.

SENIOR PROCESS ENGINEER

Heavy responsibility in process design and development for a Ch.E. with eight to ten years' experience in petroleum or petrochemical fields. This is a permanent position with an East Coast organization known the world over for accomplishments in the design and development of oil refineries and chemical plants. The man selected must have the potential to supervise other senior process engineers.

High salary. Traveling and moving expenses paid. Unusually liberal vacation, insurance and pension plans.

Our staff knows of this opening. All replies held in strictest confidence. Please write details of experience, education, salaries received and initial salary requirements.

Box 235, Room 1201
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SENIOR PROJECT MANAGER — Permanent position on our engineering staff for a mechanical or chemical engineering graduate with eight to ten years' experience in petroleum refinery, petrochemical or chemical plant design and development. Ours is an East Coast organization known the world over for accomplishments in these fields. This position requires the capacity to assume immediate and complete responsibility for the coordination of the activities involved in this endeavor. There is considerable customer and vendor contact. Our salary offer is high, and in addition we have a liberal pension plan, an accumulative vacation policy, executive insurance and many other employee benefits. We will assume the expense incurred by traveling and moving to this area. Please write details of experience, education, salaries received and initial salary requirements. Complete privacy is guaranteed. Our personnel know of this opening. Box 5-12.

EXCEPTIONAL OPPORTUNITY

For chemical or mechanical engineer under thirty with truly outstanding scholastic record and potential to grow quickly into position of responsibility requiring unusual technical ability and interest in administration and sales. Specific experience is secondary to ability. We are a young, vigorous corporation run by engineers designing and selling complete plants. Reply with complete résumé to Box 27-12.

SITUATIONS WANTED

A.I.Ch.E. Members

CHEMICAL ENGINEER—PRODUCTION MANAGEMENT—Age 36. M.Ch.E. Twelve years' experience includes resident manager of alcohol plant; chief engineer of eight plant organization; assistant to vice president in charge of production. Seeking responsible position in production, management or plant engineering. Box 3-12.

SEASONED CHEMICAL ENGINEER—Sixteen years practice, seeks permanent responsible technical supervisory position. Background includes administrative experience in research, development, design, operation and technical service in petroleum, petrochemical and A.E.C. fields. Professional degree, Q-cleared. Age 39, married. Indicate salary range. Box 4-12.

SALES ENGINEERING OR TECHNICAL SERVICE—B.Ch.E., M.B.A. credits toward doctorate. Age 33, married, veteran. Eight years' industrial experience, four years in active selling and four years in development and research. Willing to travel. Box 10-12.

CHEMICAL ENGINEER—B.Ch.E. 1950. Three years' experience includes 2½ years process design, equipment design, layout, specifications, and procurement, with leading chemical manufacturer. Six months liaison engineer between development and procurement. Age 26, single, veteran. Available immediately. Box 11-12.

CHEMICAL-MECHANICAL ENGINEER—Degrees, Dresden and Karlsruhe. Associate member A.I.Ch.E., M.E.I.C., P.E. Lecturer at McGill University. Fifteen years' experience as plant engineer and assistant manager in heavy industrial and chemical plants, process and design. French, German, some Spanish and Swedish. Single. Box 12-12.

CHEMICAL ENGINEER — B.S., M.S. Four years' diversified experience, six months extensive European travel. Seek position dealing primarily with people and equipment. Location immaterial. Box 13-12.

YOUNG CHEMICAL ENGINEER — B.Ch.E. 1952. Recently released from Air Force. Present position in process engineering. Desire position in production or development, in Northern Great Lakes area. Box 14-12.

CHEMICAL ENGINEER—M.S. 1947, M.I.T. Ten years' experience research and administration, cost estimating, budgeting, market research, progress reporting, research library administration, editing, writing, control accounting. Three publications. St. Louis area, will relocate. Seeking responsibility in research administration. Box 15-12.

CHEMICAL ENGINEER—Age 31. Ten years' diversified experience including engineering administration, customer relations, product promotion, technical sales, business administration and plant development. Seeking greater opportunity and responsibility in challenging position with stable future. Box 16-12.

CHEMICAL ENGINEER—M.Ch.E. with 8½ years' experience in plant design and process development of organic chemicals. Desire position requiring coordinating and planning as well as the technical ability to carry projects through to completion. West Coast preferred Box 17-12.

CHEMICAL ENGINEER—B.Ch.E., 1950. Age 24, married, child. Two years' experience as production supervisor; one year in pilot plant and engineering. Helped start operations in fine and intermediate chemical processes. Desire position in process design or engineering related to manufacturing. Box 18-12.

TECHNICAL SALES OR SERVICE desired. Consider development or administrative position with more responsibility and freedom of movement. M.S.Ch.E. Eight years' heavy chemical plant and laboratory process development; two years' pharmaceutical experience. Patents. Age 35, veteran, family. Desire to relocate South: eastern coastal, New Orleans, Los Angeles. Will consider foreign travel or location. Box 19-12.

CHEMICAL PROCESS-PROJECT ENGINEER —M.S. Twelve years' experience in petroleum, petrochemicals, cellulosic and organic chemicals. Available for highly responsible position in management branch of expanding aggressive company. Location secondary to opportunity. Box 20-12.

CHEMICAL ENGINEER-SALES — B.S. 1948. Age 30, married. 5½ years' experience selling to chemical industries in the South. Particularly familiar with Louisiana, Mississippi and Alabama. Now employed, but desire opportunity with progressive company. Good appearance, nice personality and quick to learn. Own home in New Orleans but no objection to another southern city. Box 21-12.

CHEMICAL ENGINEER—Age 34. B.S. University of Illinois. West Point graduate, M.S. M.I.T. Practice School. Diversified experience research and development, administration, teaching chemistry and chemical engineering. Army officer available June. New England preferred. Box 22-12.

CHEMICAL ENGINEER—B.Ch.E. Age 31, married. Nine years' progressive experience; trouble shooting, development, production and industrial engineering supervision. Strong in planning and cost control. Seek responsible staff position. Box 23-12.

COST REDUCTION — Active member A.I.Ch.E., licensed industrial and chemical engineer. Two years production heavy chemicals and TNT, seven years petroleum economic studies, two years industrial engineer in steel mill. Patents. Experience in methods studies, standard costs, and incentive plans. Want position as chief methods engineer handling methods studies, suggestion plan, appropriation requests, etc., either as consultant or employee. Age 33, single. Prefer Midwest. Willing to travel. $9,000. Box 24-12.

PEOPLE
(Continued from page 69)

The appointment of **J. E. Troyan** as vice-president and general manager and of **Don W. Ryker** as assistant general manager has been announced by Matholin Corp. which was recently formed by Mathieson Chemical Corp. and Olin Industries, Inc. They will be located at the company's headquarters office in Baltimore. Mr. Troyan, who has been manager of process development in the chemical research and engineering division of Mathieson, joined that company in 1949. He was formerly associated with Phillips Petroleum Co., and Gulf Research and Development Co. For two years during World War II he served in the Office of the Rubber Director, War Production Board.

Mr. Ryker has been with Olin Industries at East Alton, Ill., for the past seven years, most recently as manager of hydrazine research. He received his chemical engineering degree from the University of Michigan.

Earl D. York has joined the staff of the Whiting Research Laboratories of Standard Oil Co. (Ind.). He obtained his B.S. degree in chemical engineering at Purdue University, and has recently been associated with the Oak Ridge National Laboratory.

PROJECT ENGINEER—P.E. Presently consultant in plant layout and equipment design. Available on consultant arrangement to firm requiring engineer for project management or assistance in obtaining new work. New York area preferred. Box 25-12.

CHEMICAL ENGINEER—30. Looking for responsible position utilizing ten years' diversified experience in organic, inorganic, and petroleum fields. Abilities include cost estimating, instrumentation, design, economic studies and a proven record in dealing with people. $8,000. Box 28-12.

CHEMICAL ENGINEER—M.S. 1950. Experience includes petroleum research and development (vapor liquid equilibrium studies, design, etc.) sanitary engineering, and college teaching. 5213 Parkview Avenue, Westfield, N. J.

Nonmembers

CHEMICAL ENGINEER—B.Ch.E. 1950. Age 31. Three years production and development on all unit operations. Excellent break-in trouble shooting experience and knowledge of chemical process equipment. Desire opportunity for assignment to other departments in future. (Sales, service, etc.) Ultimate objective — managerial position. Box 26-12.
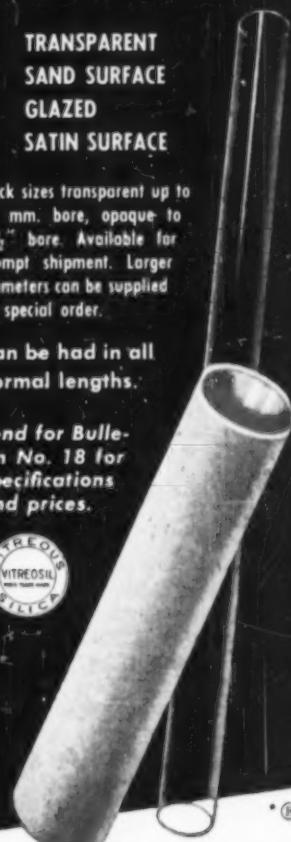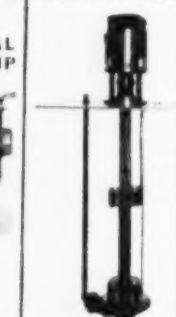
DIRECTIONS FOR USE OF CLASSIFIED SECTION

Advertisements in the Classified Section of Chemical Engineering Progress are payable in advance at 15c a word, with a minimum of four lines accepted. Box number counts as two words. Advertisements average about six words a line. Members of the American Institute of Chemical Engineers in good standing are allowed one six-line Situation Wanted insertion (about 36 words) free of charge a year. More than one insertion to members will be made at half rates. In using the Classified Section of Chemical Engineering Progress it is agreed by prospective employers and employees that all communications will be acknowledged, and the service is made available on that condition. Boxed advertisements are available at $15 a column inch. Size of type may be specified by advertiser. In answering advertisements all box numbers should be addressed care of Chemical Engineering Progress, Classified Section, 120 East 41st Street, New York 17, N. Y. Telephone ORegon 9-1560. Advertisements for this section should be in the editorial offices the 15th of the month preceding the issue.

G. A. Webb has been appointed assistant to the manager of the research department of Koppers Company, Inc. Dr. Webb, formerly in the position of executive secretary of the new products committee, will plan technical research activities, prepare special studies on specific research projects, and coordinate other department activities with market research investigation. He became affiliated with the company in 1941 under a Koppers Fellowship at Mellon Institute where, until 1943, he was in charge of certain catalytic developments.

Necrology

Gaston F. DuBois, consulting engineer and former officer and director of Monsanto Chemical Co., died Nov. 1.

He joined the newly formed Monsanto Chemical Co. in 1904 as the third member of the young company's management. His connection with the company was unbroken until his retirement in 1945 when he remained a member of the company's board of directors until March, 1949. He was production manager of Monsanto from 1913 to 1920, when he was named vice-president and technical director. He served as president from 1919 to 1923, and then returned to directing the company's technical activities. In 1930, he was made vice-president in charge of research and development and became a member of the company's Executive Committee in 1939. Educated at the Federal Polytechnic Institute at Zurich, Switzerland, he received a degree in chemical engineering in 1903, and this was followed by a postgraduate course in electrochemistry at the Technische Hochschule, Dresden, Germany.

A foremost figure in the development of the American chemical industry, Mr. DuBois was the recipient of many awards.

D. F. RYNNING

Delroy F. Rynning, engineer with Shell Development Co., Emeryville, Calif., died Nov. 3, 1953. He received his B. S. and M.S. degrees from Oregon State College, and had previously been associated with the General Chemical Co., El Segundo, Calif. Mr. Rynning served on the Publicity Committee for the recent A.I.Ch.E. San Francisco Meeting and was editor of the *San Francisco Engineer*.

R. K. STONE

R. King Stone, manufacturer's agent, Ross-Meehan Foundries, Chattanooga, Tenn., died recently. Early in his career he was affiliated with the Hercules Powder Co., Tyner, Tenn.

INDEX OF ADVERTISERS

Advertising Offices

THE PRESIDENT SAYS

In 1904, some four years before A.I.Ch.E. was founded, Andrew Carnegie made a handsome present of one and a half million dollars to the National Societies of Mechanical, Electrical and Mining Engineers and the Engineers' Club of New York. The purpose of the gift was, in Mr. Carnegie's own words, "for the erection of a suitable union home for you all in New York City." This gift was divided, about two thirds toward construction of the Engineering Societies Building and one third for The Engineers' Club. The civil engineers did not join in the Engineering Societies Building at the time since they had completed their own headquarters in 1897. However, in 1917 they moved into the joint headquarters and were received as the fourth Founder Society.

At one time A.I.Ch.E. had its headquarters in the Engineering Societies Building. Inability to secure enough space eventually forced it out into other quarters in The Chemists' Club Building. This was unfortunate, in my opinion, for we have never since been as close as we should have been to the other major engineering societies. All of these groups have grown rapidly and such other societies as Engineers Council for Professional Development and Engineers Joint Council have come into being to handle certain matters of importance to engineers. Quite a lot of pressure has been developing in the direction of larger quarters, and it is obvious that any such consideration ought to include societies other than those now residing in the building. Just as soon as a definite idea aimed at a new set-up developed, the possibility of moving to another city was inevitable. There are many fine cities which might be suitable but, for one reason or another, four seem most prominent in the picture, namely New York, Washington, Pittsburgh, and Chicago. No doubt an engineering societies center would be an asset to any of these communities and likely any one of them would strive, through their municipal government and civic organizations, to provide financial or other assistance. As a matter of fact, interested civic leaders in Pittsburgh and Chicago have been most kind and helpful, and in both cases there is evidence that the societies could count upon the community for assistance of a substantial sort.

From the operating standpoint, it is apparent that there would be great advantages to our societies in having their headquarters in the central part of the country. The population trend is westward and increasingly members of governing boards and committees are coming from western areas. New York has been headquarters for so long that there is a lot of inertia in even thinking of moving away. Once this inertia is overcome, many attractive features are perceptible in a Pittsburgh or Chicago location. Pittsburgh is in the throes of a gigantic program which is transforming the city where I grew up. An engineering societies center would be a feature of its civic building program. In Chicago the three universities are spearheading the movement to bring before the engineering societies the virtues of their city as a headquarters location. Political and civic leaders in Chicago have evinced considerable interest in supplying assistance to make the dream come true. The more I hear of this plan for a new engineering societies center, the more enthusiasm I develop. It seems to me to make good sense to consider getting closer to the geographic and population center of the country. All the major societies, at least, need improved headquarters facilities and the events of the past fifty years certainly teach us that we must plan for expansion. Such a move would be a wonderful help in continuing to move toward increased unity in the engineering profession.

Certainly, if a new center is to be erected, wherever it may be, A.I.Ch.E. ought to be part of it. I think we should resolve to be in the deal and to assume the position that our size and strength entitle us to assume. We have a current problem, as I have said before. We could tough that out for awhile if a serious plan is afoot to lick our problem permanently. I hope every member of A.I.Ch.E. will support strongly whatever plan our Council recommends. Meanwhile, rest assured that A.I.Ch.E. will take an active part in the deliberations that are in progress.

* * * * * *

This, my friends, is the last column in the series which I have devoted to telling you a little something about what goes on. I know some of you have liked the idea and I hope all of you have somehow been helped. Whether President Kirkbride will do something of the sort, I am not sure, but I am confident that he will find some way to keep you posted. And, do not forget the credo of the chemical engineer: *Illegitimis Non Carborundum.*

W. J. Nichols

C. G. Kirkbride
B. F. Dodge
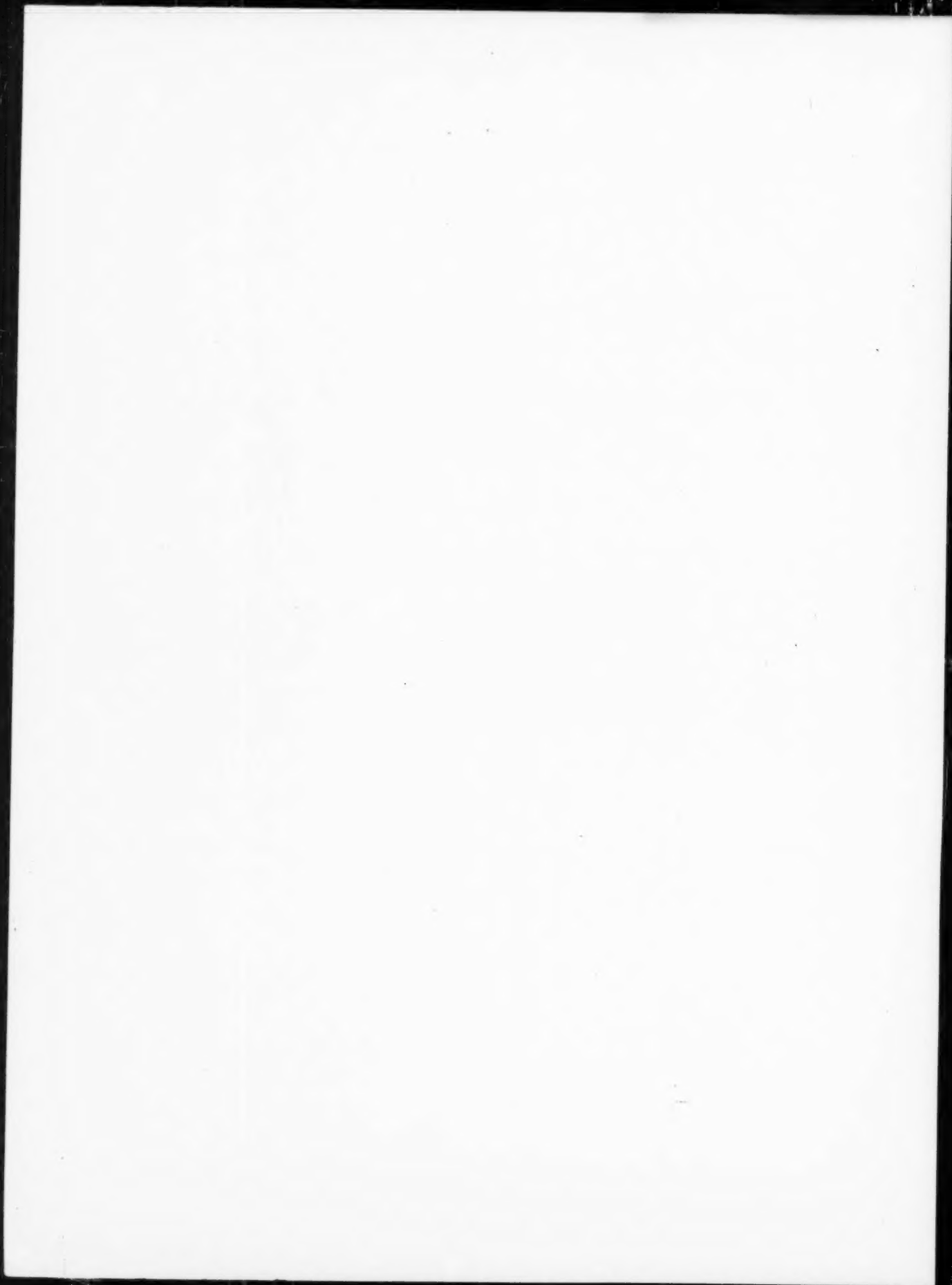L. P. Scoville

R. P. Dinsmore
G. E. Holbrook
W. L. Faith

Once again the members of the American Institute of Chemical Engineers have elected their officers by a record vote, nearly 300 more ballots being cast this year than in 1952. Of the four top offices, only the vice-presidency was contested. The president for 1954 is Chalmer G. Kirkbride, president and director of Houdry Process Corp. In a close race Barnett F. Dodge, professor of chemical engineering at Yale University, was elected vice-president over Earl P. Stevenson, president of Arthur D. Little, Inc. Other members nominated for the office, who declined for various reasons, were C. G. Kirkbride, who was a candidate for the presidency, G. G. Brown, who declined in order to run for treasurer, G. E. Holbrook, who declined and became a candidate for director, and R. C. Gunness, of Standard Oil (Indiana) Co. Treasurer of the Institute is George Granger Brown, dean of the college of engineering at the University of Michigan, who was appointed to the office by Council in the middle of this year on the resignation of Carl R. DeLong, treasurer for 16 years. Stephen L. Tyler, secretary and executive secretary of the A.I.Ch.E.

since 1937, was reelected by the largest number of votes cast for any one officer.

Of the twelve candidates for director, the four with the greatest number of votes, who consequently were elected, were Loren P. Scoville, vice-president of Jefferson Chemical Co., who received 1,464 votes; Ray P. Dinsmore, vice-president of Goodyear Tire and Rubber Co., 1,434 votes; George E. Holbrook, assistant director, development department, DuPont Co., 1,303 votes, and W. L. Faith, director of engineering, chemical division, Corn Products Refining Co., 928 votes. A total of nineteen members were nominated for the directorships, but the number of candidates is constitutionally limited to the twelve highest on the slate.

The total number of valid votes cast in the mail ballot was 2,791, out of a total active membership of 4,805, according to the report of the Tellers' Committee, headed by F. B. White, Foster Wheeler Corp., and consisting of S. B. Adler, The M. W. Kellogg Co.; W. T. Dorsheimer, DuPont Co.; H. L. Malakoff, Cities Service Petroleum, Inc.; and Richard Morton, chemical engineering representative.
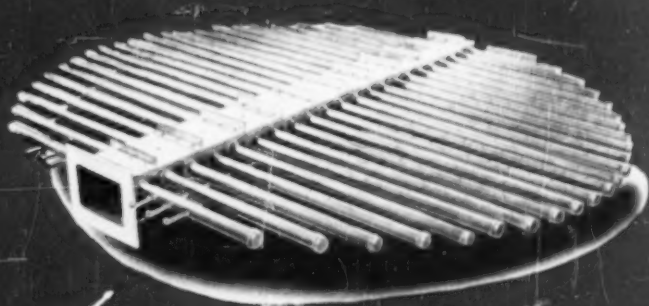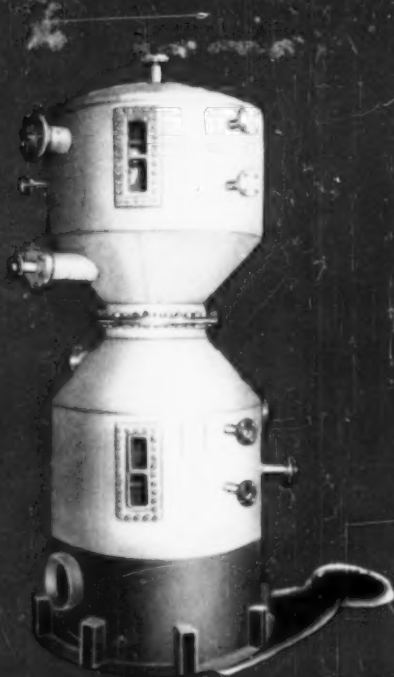
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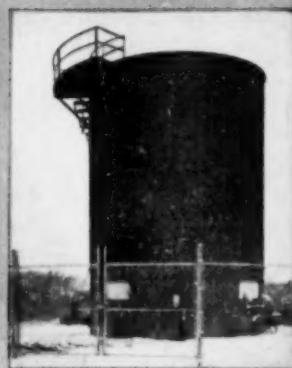
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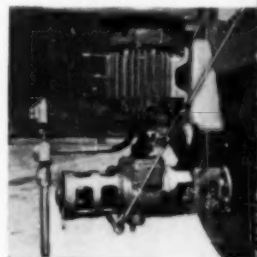
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☐ B-102 Top Entering Mixers (turbine and paddle types)
☐ B-103 Top Entering Mixers (propeller type)
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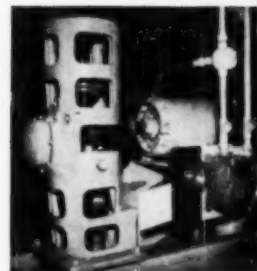☐ B-105 Condensed Catalog (complete line)
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